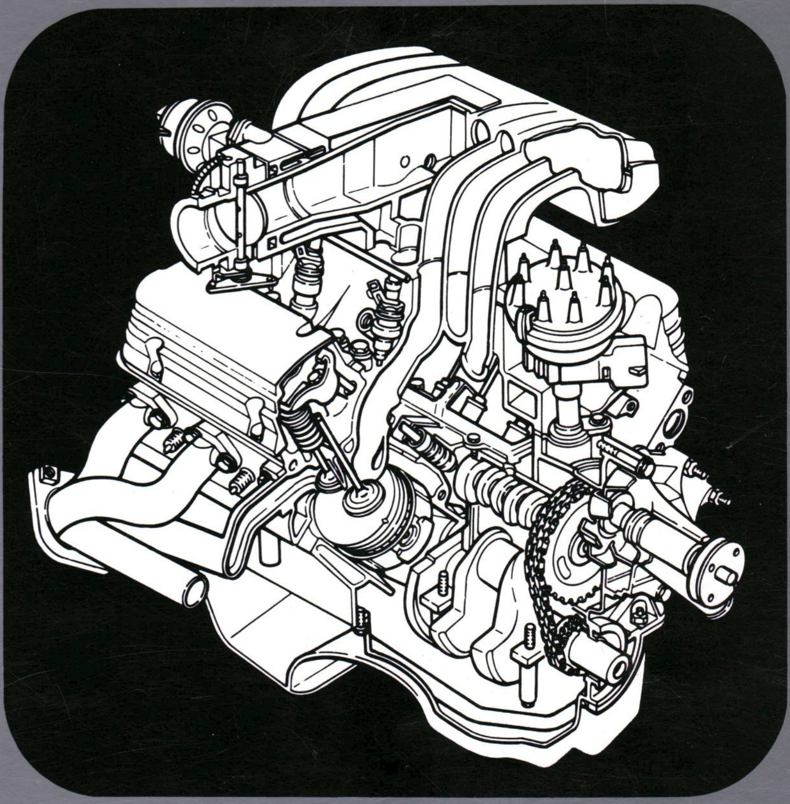
the effect of engine design on emissions and performance



Supplement to Select STST Courses

STST
Service Technician Specialty Training
Ford Parts and Service Division
Technical Training

IMPORTANT SAFETY NOTICE

Appropriate service methods and proper repair procedures are essential for the safe, reliable operation of all motor vehicles, as well as the personal safety of the individual doing the work. This manual provides general directions for accomplishing service and repair work with tested, effective techniques. Following them will help assure reliability.

There are numerous variations in procedures, techniques, tools, and parts for servicing vehicles, as well as in the skill of the individual doing the work. This manual cannot possibly anticipate all such variations and provide advice or cautions as to each. Accordingly, anyone who departs from instructions provided in this manual must first establish that he compromises neither his personal safety nor the vehicle integrity by his choice of methods, tools or parts.

As you read through the procedures, you will come across NOTES, CAUTIONS, AND WARNINGS. Each one is there for a specific purpose. NOTES give you added information that will help you to complete a particular procedure. CAUTIONS are given to prevent you from making an error that could damage the vehicle. WARNINGS remind you to be especially careful in those areas where carelessness can cause personal injury. The following list contains some general WARNINGS that you should follow when you work on a vehicle.

- Always wear safety glasses for eye protection.
- Use safety stands whenever a procedure requires you to be under the vehicle.
- Be sure that the ignition switch is always in the OFF position, unless otherwise required by the procedure.
- Set the parking brake when working on the vehicle. If you have an automatic transmission, set it in PARK unless instructed otherwise for a specific service operation. If you have a manual transmission, it should be in REVERSE (engine OFF) or NEUTRAL (engine ON) unless instructed otherwise for a specific service operation.
- Operate the engine only in a well-ventilated area to avoid the danger of carbon monoxide.
- Keep yourself and your clothing away from moving parts when the engine is running, especially the fan and belts.
- To prevent serious burns, avoid contact with hot metal parts such as the radiator, exhaust manifold, tail pipe, catalytic converter and muffler.
- Do not smoke while working on the vehicle.
- To avoid injury, always remove rings, watches, loose hanging jewelry, and loose clothing before beginning to work on a vehicle. Tie long hair securely behind your head.
- Keep hands and other objects clear of the radiator fan blades. Electric cooling fans can start to operate at any time by an increase in underhood temperatures, even though the ignition is in the OFF position. Therefore, care should be taken to ensure that the electric cooling fan is completely disconnected when working under the hood.

The recommendations and suggestions contained in this manual are made to assist the dealer in improving his dealership parts and/or service department operations. These recommendations and suggestions do not supersede or override the provisions of the Warranty and Policy Manual or the Shop Manual and in any cases where there may be a conflict, the provisions of the Warranty and Policy Manual or the Shop Manual shall govern.

The descriptions, testing procedures, and specifications in this handbook were in effect at the time the handbook was approved for printing. Ford Motor Company reserves the right to discontinue models at any time, or change specifications, design, or testing procedures without notice and without incurring obligation. Any reference to brand names in this manual is intended merely as an example of the types of tools, lubricants, materials, etc. recommended for use. Equivalents, if available, may be used. The right is reserved to make changes at any time without notice.

WARNING: Many brake linings contain asbestos fibers. When working on brake components, avoid breathing the dust. Breathing the asbestos dust can cause asbestosis and cancer.

Breathing asbestos dust is harmful to your health.

Dust and dirt present on car wheel brake and clutch assemblies may contain asbestos fibers that are hazardous to your health when made airborne by cleaning with compressed air or by dry brushing.

Wheel brake assemblies and clutch facings should be cleaned using a vacuum cleaner recommended for use with asbestos fibers. Dust and dirt should be disposed of in a manner that prevents dust exposure, such as sealed bags. The bag must be labelled per OSHA instructions and the trash hauler notified as to the contents of the bag.

If a vacuum bag suitable for asbestos is not available, cleaning should be done wet. If dust generation is still possible, technicians should wear government approved toxic dust purifying respirators.

OSHA requires areas where asbestos dust generation is possible to be isolated and posted with warning signs. Only technicians concerned with performing brake or clutch service should be present in the area.

Copyright © 1988 Ford Motor Company

TABLE OF CONTENTS

COURSE OBJECTIVES 1

INTRODUCTION 2
- History 2
- Purpose of This Course 2

REVIEW OF ENGINE OPERATION 4
- Four-Stroke Cycle 4
  - Intake Stroke 4
  - Compression Stroke 4
  - Power Stroke 5
  - Exhaust Stroke 5
- Basic Engine Components and How They Work Together 5
  - Cylinder Block 5
  - Pistons and Crankshaft 5
  - Cylinder Head, Valve Train, and Camshaft 5
- Engine Operation 7

CONCEPTS OF ENGINE DESIGN 9
- Friction 9
- Volumetric Efficiency 9
- Control of Combustion 9
  - Lean-Burn and Fast-Burn 9
  - Turbulence and Swirl 9
  - Surface Quenching 10
- Compression Ratio 11
- Weight Reduction 11
- Strength 11
- Bore/Stroke Ratio 11

CYLINDER HEAD/COMBUSTION CHAMBER 14
- Cylinder Head Description 14
- Materials 14
  - Cast Iron 14
  - Cast Aluminum 14
- Cylinder Head/Combustion Chamber Design 15
  - Basic Combustion Chamber Designs 16
  - Other Design Considerations 20
  - Sample Design 22

PISTONS 24
- Description 24
- Piston Materials 25
  - Cast Iron 25
  - Aluminum 25
  - Aluminum Alloys 26
- Connecting Rod Materials 26
  - Steel 26
  - Powdered Metal 26
- Ring Materials 26

TABLE OF CONTENTS

Design 26
  Dished Pistons 26
  Flat-Topped Pistons 26
  Domed Pistons 26
  Rings 29

CAMSHAFT 32
  Description 32
  Materials 32
  Design 33
    Lift, Duration, and Overlap 33
    Roller Cam 33
    Overhead Cam 33
    Double Overhead Cam 33

VALVE TRAIN 36
  Description 36
    Valving for In-Block Cam Engines 36
    Valving for Overhead Cam Engines 37
    Valve Train Components 37
  Design 41
    Shapes of Valves 41
    Positive Rotators 41
    Roller Hydraulic Lifters 41
    Finger Followers 44
    Low Force Compression Valve Spring 44
    High Force Valve Spring 44

CYLINDER BLOCK 45
  Description 45
  Materials 45
    Cast Iron 45
    Low Friction Block 46
  Design 46

CRANKSHAFT 47
  Description 47
  Materials 47
    Torsional Stiffness 47
    Cast Nodular Iron 47
    Forged Alloy Steel 49
  Design 49
    Redesigned V-6 Engine Crankshaft 49
    Fillet Rolling 49
    Machining the Counterweights 49
    Harmonic Balancers 49

CONNECTING ROD BEARINGS AND MAIN BEARINGS 50
  Description 50
  Materials 50
  Design 51

TABLE OF CONTENTS

INTAKE MANIFOLD 52
  Description 52
  Materials 52
    Cast Iron 52
    Cast Aluminum 52
  Design 54
    Dual Plane Intake Manifold 54
    Tuned Intake Manifolds 54

EXHAUST MANIFOLD 56
  Description 56
  Materials 56
    Cast Iron 56
    Cast Nodular Iron 56
    Fabricated Steel 56
  Design 56
    Tuned Exhaust Manifolds 56

SPECIAL INNOVATIONS 58
  Balance Shafts 58
  Low Drag Oil and Water Pumps 58

NEW ENGINE MATERIALS AND TECHNOLOGY 60
  Introduction: Improving the Standard Design 60
  New Materials 60
  New Engine Designs 62
    Gerace Engine 62
    Sterling Engine 62
    Reciprocating Engines 62

CONCLUSION 62

GLOSSARY 67

COURSE OBJECTIVES

After completing this course, the technician will be able to describe how design changes in the following engine components affect engine performance and emissions.

- Cylinder block
- Camshaft
- Crankshaft
- Cylinder head
- Valve train
- Pistons (including rings and connecting rods)
- Intake and exhaust manifolds

INTRODUCTION

HISTORY

The automotive internal combustion engine has been changing since its invention in the nineteenth century. Automobile manufacturers have tried different designs and used different materials in the effort to build engines that offer better performance, improved fuel economy, and reduced exhaust emissions. Many design features that have become popular recently were actually developed long ago. For example, double overhead cam engines were around more than fifty years ago (Fig. 1). However, automotive engine changes have come faster in recent years because, while government regulations have required better fuel economy and lower exhaust emissions, consumers have continued to demand good performance.

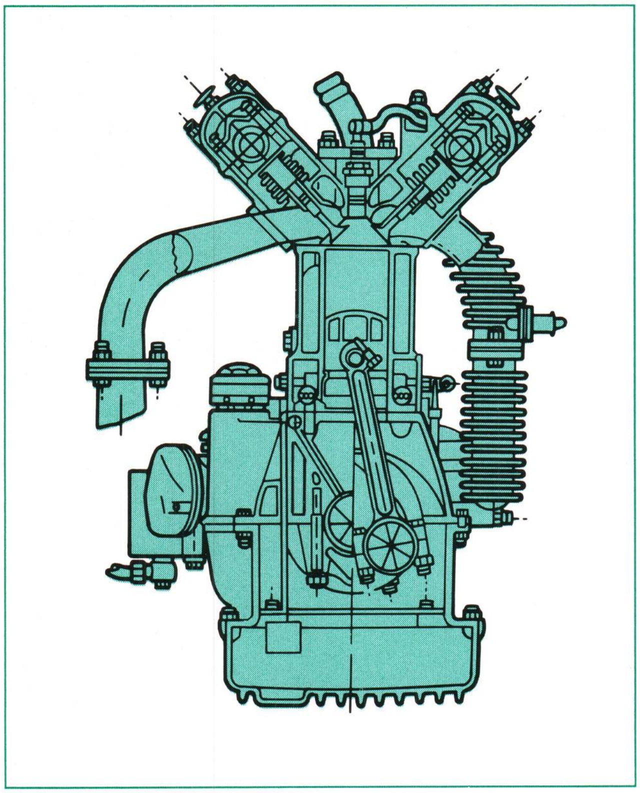


Figure 1 — Alfa Romeo 6C 1500 — 1928

PURPOSE OF THIS COURSE

To meet both government and consumer requirements, automobile manufacturers have made changes in almost every engine subsystem, including fuel delivery, air intake, ignition, emissions control, and mechanical systems. In this course, we will concentrate on changes in the engine mechanical systems, including the following components (Fig. 2):

- Cylinder block
- Cylinder head
- Crankshaft
- Camshaft
- Pistons (including rings and connecting rods)
- Valve train
- Intake and exhaust manifolds

We will see how changes in these components have improved engine operation, producing better performance, increased fuel economy, and reduced exhaust emissions. We will also see how a change in one area usually requires changes in other areas. For instance, a different valve train design may require a new camshaft, or improved combustion chamber design may lead to less spark advance. Remember, no part of the engine operates by itself. All components and subsystems must be designed to work **together** for the engine to run well.

INTRODUCTION

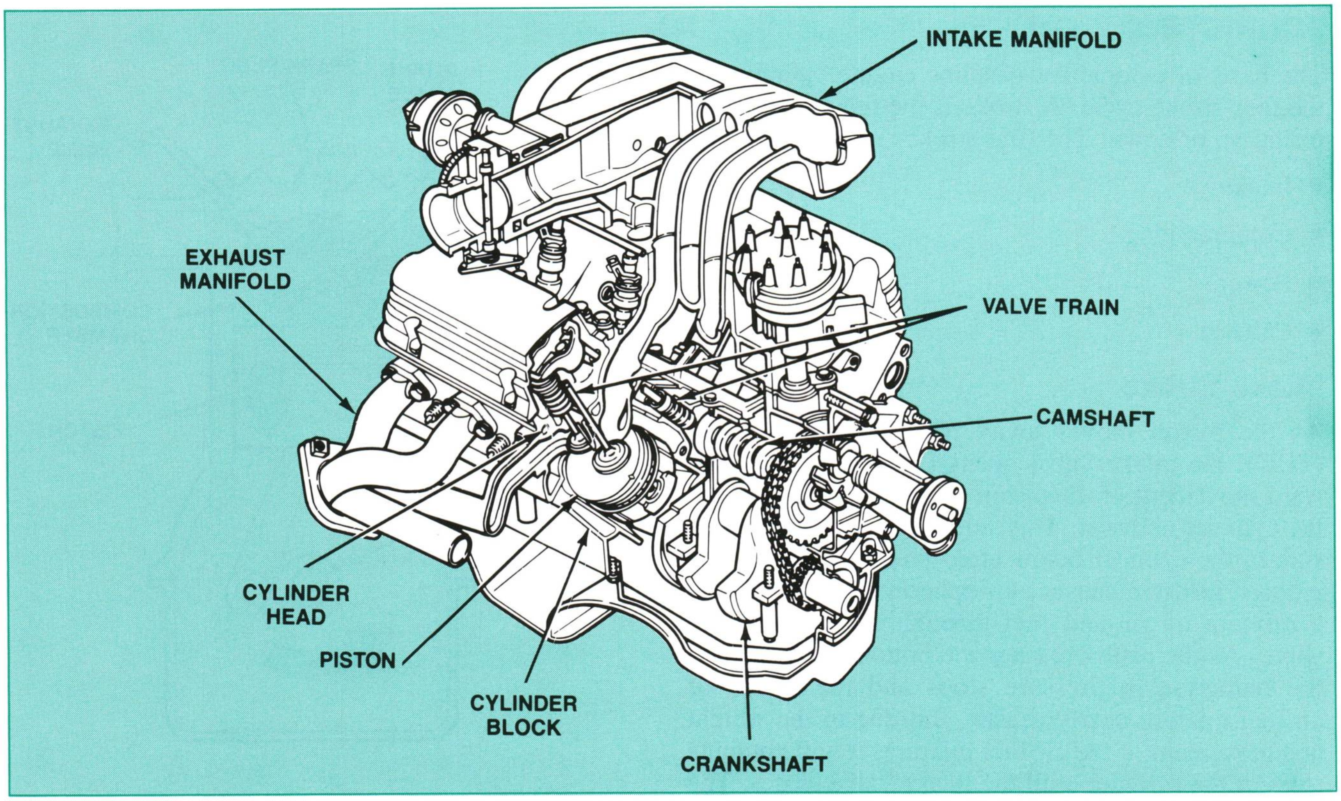

INTAKE MANIFOLD
EXHAUST MANIFOLD
VALVE TRAIN
CAMSHAFT
CYLINDER HEAD
PISTON
CYLINDER BLOCK
CRANKSHAFT

Figure 2 — Engine Mechanical Components

REVIEW OF ENGINE OPERATION

FOUR-STROKE CYCLE

The basis of automotive gasoline engine operation is the four-stroke cycle. A stroke is the full travel of the piston up or down. The four strokes in this cycle are:

- Intake
- Compression
- Power
- Exhaust

Intake Stroke

As the piston moves away from top dead center (TDC), the intake valve opens (Fig. 3). The downward movement of the piston increases the volume of the cylinder above it. This, in turn, reduces the pressure in the cylinder below atmospheric pressure. The reduced pressure causes atmospheric pressure to push a mixture of air and fuel through the open intake valve. As the piston reaches the bottom of its stroke, the reduction in pressure stops and the intake of air/fuel mixture nearly ceases. But due to the weight and movement of the air/fuel mixture, it will continue to enter the cylinder until the intake valve closes. The delayed closing of the intake valve increases the volumetric efficiency of the cylinder by packing as much air and fuel into it as possible. Volumetric efficiency describes how the engine breathes and will be discussed in greater detail under "Concepts of Engine Design" in this manual.

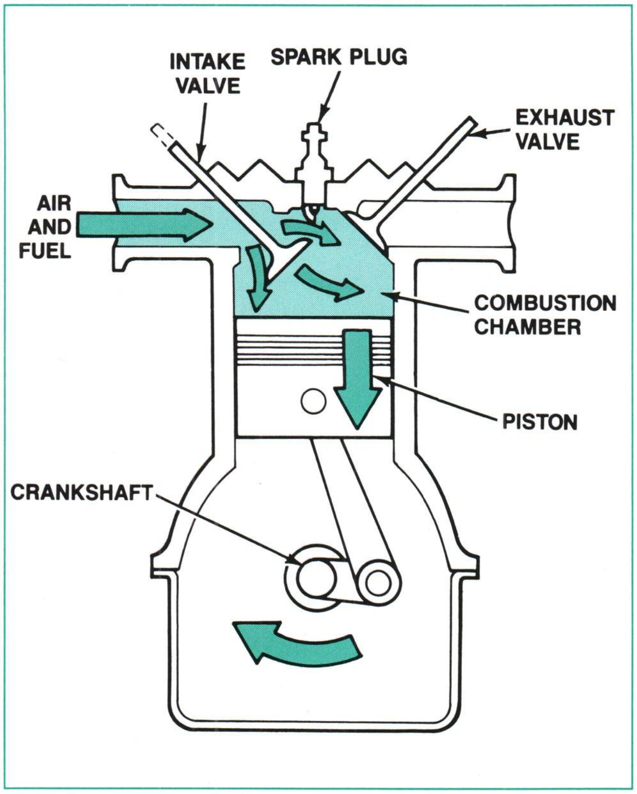


Figure 3 — Intake Stroke

Compression Stroke

The compression stroke begins as the piston starts to move from bottom dead center (BDC). The intake valve closes, trapping the air/fuel mixture in the cylinder (Fig. 4). Upward movement of the piston compresses the air/fuel mixture. At TDC, the piston and cylinder walls form a combustion chamber in which the fuel will be burned. The volume of the cylinder with the piston at BDC compared to the volume of the cylinder with the piston at TDC determines the compression ratio of the engine. Compression ratio will be discussed later in this manual.

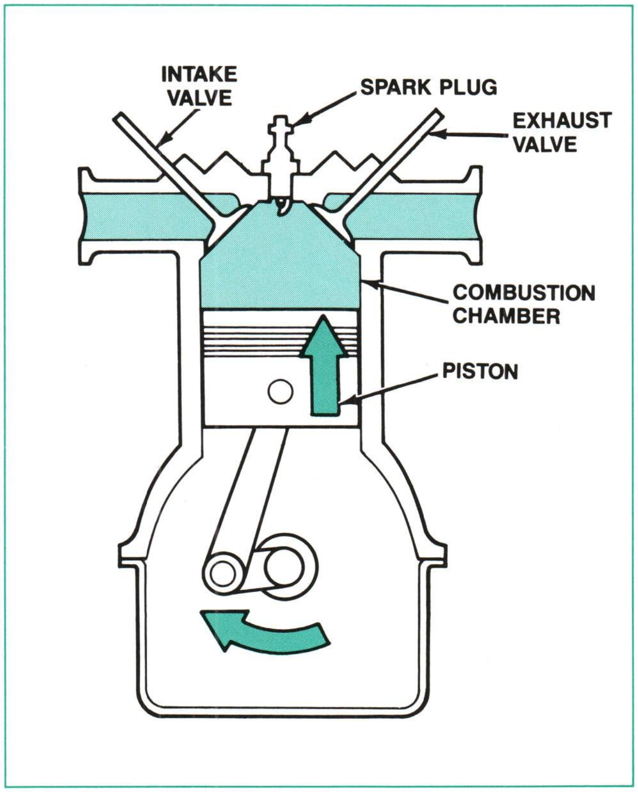


Figure 4 — Compression Stroke

Power Stroke

The power stroke begins as the compressed fuel mixture is ignited in the combustion chamber (Fig. 5). An electrical spark across the electrode of a spark plug ignites the air/fuel mixture. The burning fuel rapidly expands, creating a very high pressure against the top of the piston. This drives the piston down toward BDC. The downward movement of the piston is transmitted through the connecting rod to the crankshaft. Up-and-down movement of the piston on all four strokes is converted to rotary motion of the crankshaft.

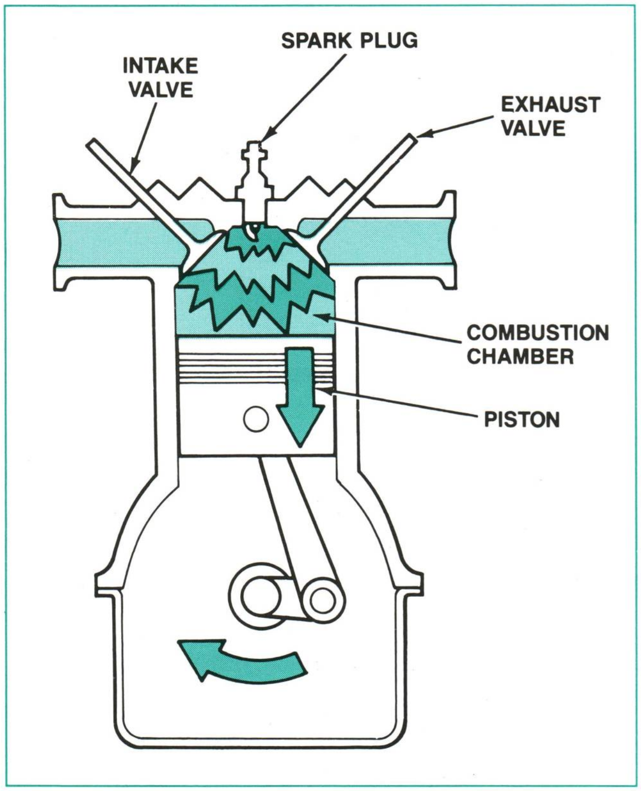


Figure 5 — Power Stroke

Exhaust Stroke

The exhaust valve opens just before the piston reaches BDC on the power stroke (Fig. 6). Pressure within the cylinder when the valve opens causes the exhaust gas to rush past the valve and into the exhaust system. Movement of the piston from BDC pushes most of the remaining exhaust gas from the cylinder. As the piston nears TDC, the exhaust valve begins to close as the intake valve starts to open.

For most engine designs, both valves are open momentarily. This condition is called valve overlap. During valve overlap, incoming air and fuel continue to purge the cylinder until the exhaust valve closes.

The exhaust stroke completes the four-stroke cycle. The opening of the intake valve begins the cycle again. This cycle occurs in each cylinder and is repeated over and over, as long as the engine is running.

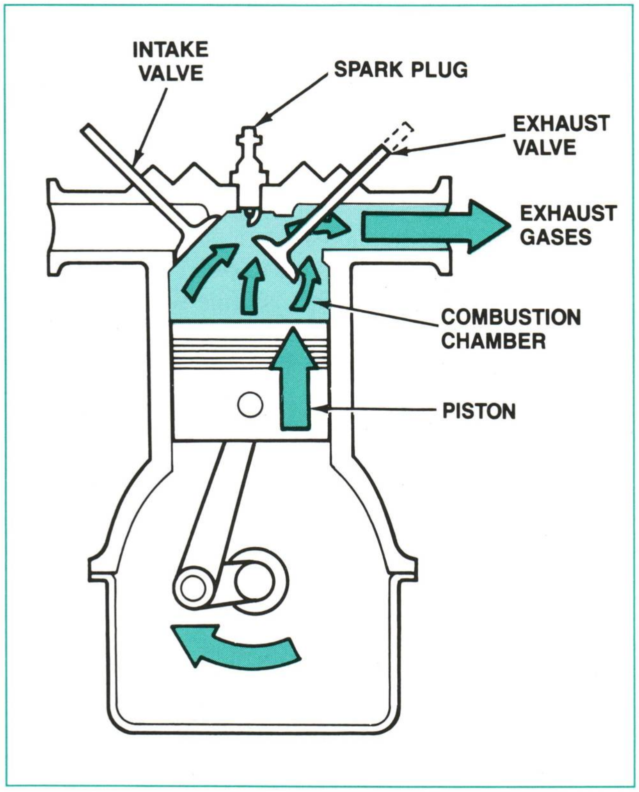


Figure 6 — Exhaust Stroke

BASIC ENGINE COMPONENTS AND HOW THEY WORK TOGETHER

Cylinder Block

The cylinder block contains the major components that transform reciprocating (up and down) force into rotary (turning) motion.

Pistons and Crankshaft

The pistons are attached to the top of the connecting rods. Each connecting rod is attached to an offset portion of the crankshaft. Combustion of the air/fuel mixture forces the piston downward in the cylinder. The force is transferred through the connecting rod to the crankshaft, which causes the crankshaft to rotate.

Cylinder Head, Valve Train and Camshaft

The top half of the engine is called the cylinder head. Today, engines use two varieties of head design: overhead valve and overhead cam.

REVIEW OF ENGINE OPERATION

In the overhead valve design (Fig. 7), the intake and exhaust valves are mounted in the cylinder head and are operated by a camshaft located in the cylinder block. This arrangement requires the use of valve lifters, push rods, and rocker arms to transfer camshaft rotation to valve movement. The intake and exhaust manifolds are attached to the cylinder head.

The overhead cam design also has intake and exhaust valves located in the cylinder head, but the camshaft is installed there as well (Fig. 8). The valves are operated directly by the camshaft and cam follower.

In either engine, the camshaft must only revolve one time in each four-stroke cycle to two complete revolutions of the crankshaft. This is done with gears, gears and a timing chain, or gears and a cogged belt that connects the crankshaft to the camshaft. For proper camshaft and valve timing, the camshaft gear must be twice the circumference of the crankshaft gear to provide this two-to-one reduction (Fig. 9).

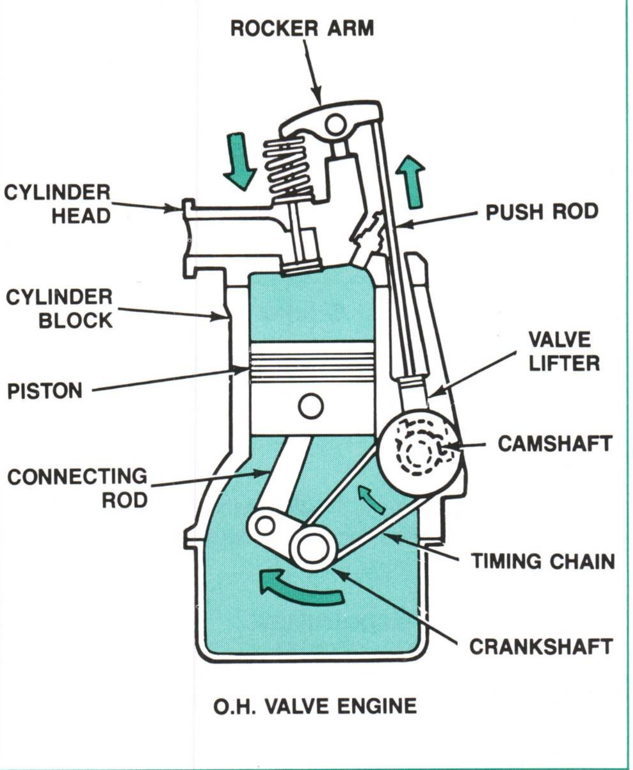

ROCKER ARM
CYLINDER HEAD
PUSH ROD
CYLINDER BLOCK
VALVE LIFTER
PISTON
CAMSHAFT
CONNECTING ROD
TIMING CHAIN
CRANKSHAFT
O.H. VALVE ENGINE

Figure 7 — Overhead Valve Engine

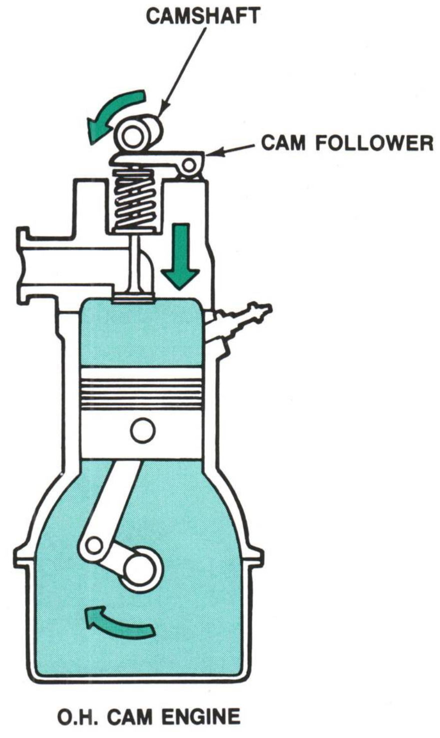
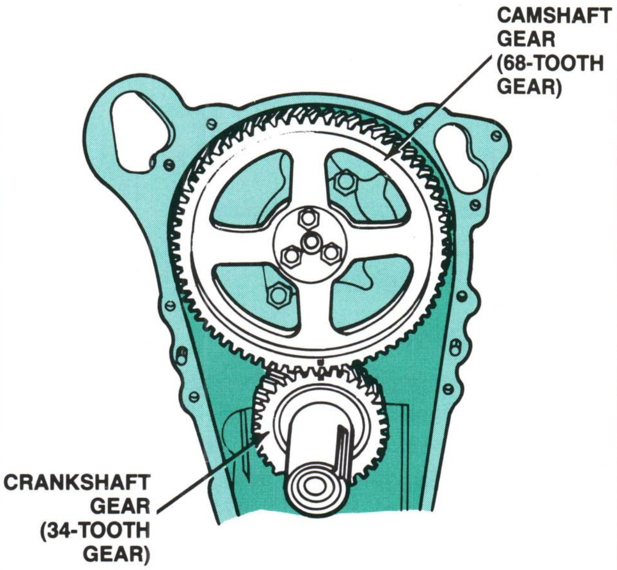

CAMSHAFT
CAM FOLLOWER
O.H. CAM ENGINE

Figure 8 — Overhead Cam Engine


CAMSHAFT GEAR (68-TOOTH GEAR)
CRANKSHAFT GEAR (34-TOOTH GEAR)

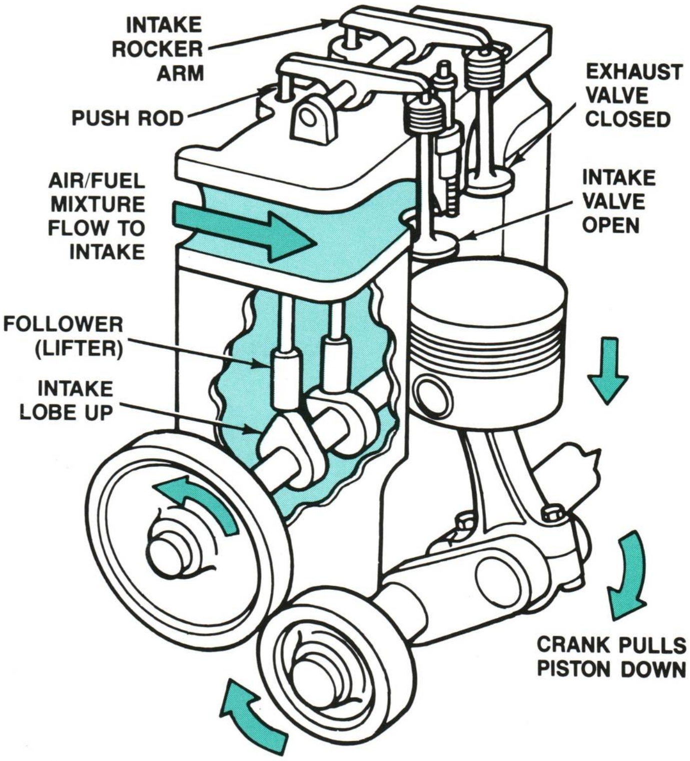
NOTE: CRANKSHAFT GEAR HAS TO MAKE TWO COMPLETE REVOLUTIONS TO TURN THE CAMSHAFT JUST ONE REVOLUTION.

Figure 9 — Two-to-One Gear Reduction

REVIEW OF ENGINE OPERATION

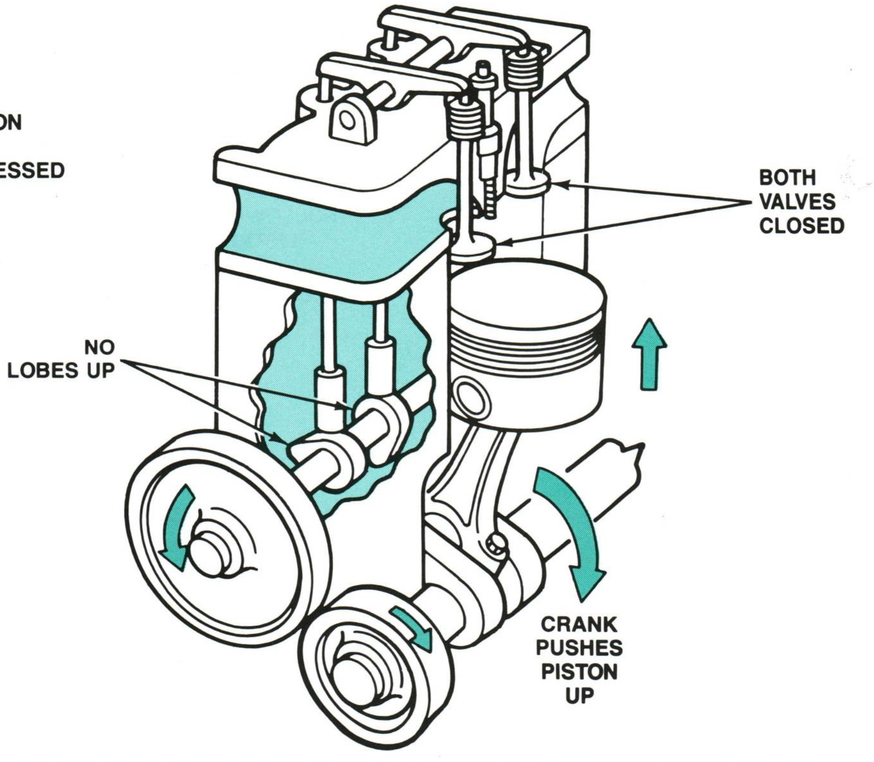
ENGINE OPERATION

The following four figures show how the basic engine components work together in a running engine. (Fig. 10-13).


INTAKE ROCKER ARM
PUSH ROD
EXHAUST VALVE CLOSED
AIR/FUEL MIXTURE FLOW TO INTAKE
INTAKE VALVE OPEN
FOLLOWER (LIFTER)
INTAKE LOBE UP
CRANK PULLS PISTON DOWN

INTAKE STROKE
- PISTON TRAVELS DOWNWARD
- CRANK MOVES 1/2 REVOLUTION
- CAM MOVES 1/4 REVOLUTION
- CAM LOBE LIFTS INTAKE VALVE FOLLOWER (LIFTER)
- FOLLOWER LIFTS PUSH ROD
- PUSH ROD LIFTS SIDE OF INTAKE ROCKER ARM, OPENING INTAKE VALVE
- AIR/FUEL MIXTURE FLOWS INTO CYLINDER THROUGH INTAKE PASSAGE

Figure 10 — Intake Stroke


BOTH VALVES CLOSED
NO LOBES UP
CRANK PUSHES PISTON UP

COMPRESSION STROKE
- PISTON TRAVELS UPWARD
- CRANK MOVES 1/2 REVOLUTION
- CAM MOVES 1/4 REVOLUTION
- AIR/FUEL MIXTURE IS COMPRESSED
- VALVES CLOSED

Figure 11 — Compression Stroke

REVIEW OF ENGINE OPERATION

POWER STROKE
- SPARK IGNITES AIR/FUEL MIXTURE
- PISTON PUSHED DOWNWARD BY COMBUSTION
- CRANK MOVES 1/2 REVOLUTION
- CAM MOVES 1/4 REVOLUTION
- VALVES CLOSED

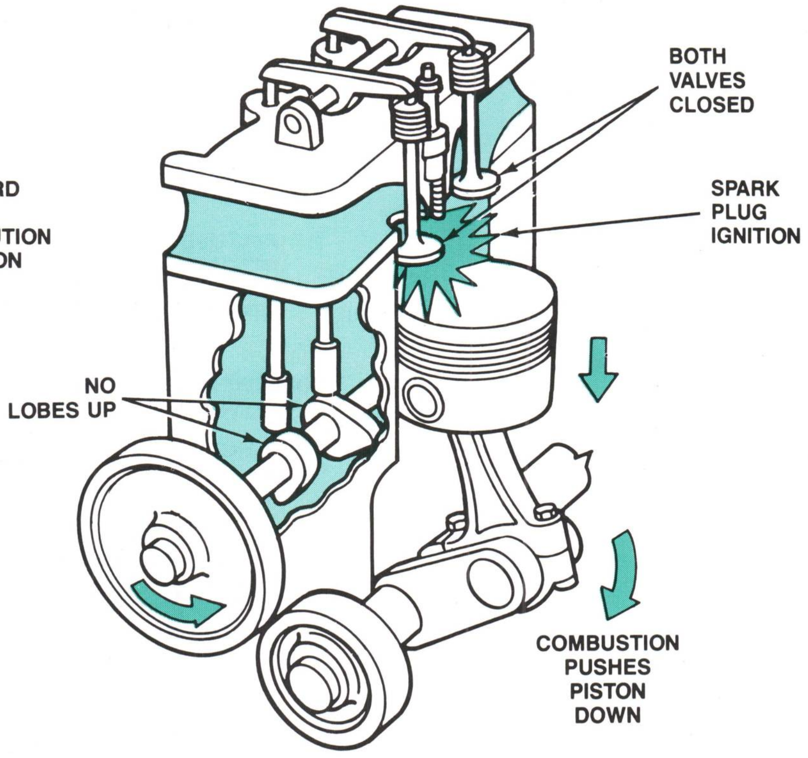

BOTH VALVES CLOSED
SPARK PLUG IGNITION
NO LOBES UP
COMBUSTION PUSHES PISTON DOWN

Figure 12 — Power Stroke

EXHAUST STROKE
- PISTON TRAVELS UPWARD
- CRANK MOVES 1/2 REVOLUTION
- CAM MOVES 1/4 REVOLUTION
- CAM LOBE LIFTS EXHAUST VALVE FOLLOWER (LIFTER)
- FOLLOWER LIFTS PUSHROD
- PUSHROD LIFTS SIDE OF EXHAUST ROCKER ARM, OPENING EXHAUST VALVE
- EXHAUST GASES ARE PURGED FROM CYLINDER

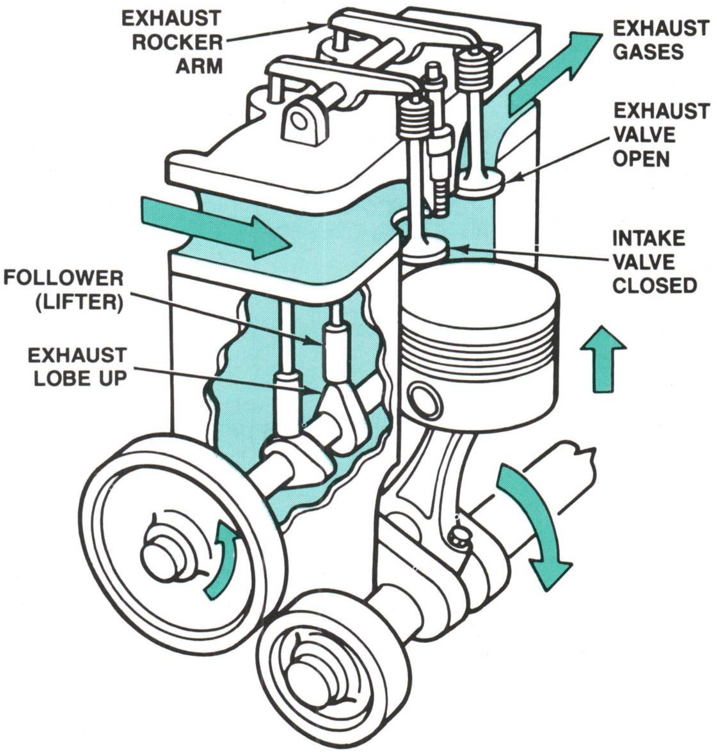

EXHAUST ROCKER ARM
EXHAUST GASES
EXHAUST VALVE OPEN
INTAKE VALVE CLOSED
FOLLOWER (LIFTER)
EXHAUST LOBE UP

Figure 13 — Exhaust Stroke

CONCEPTS OF ENGINE DESIGN

To understand how design changes affect engine performance, fuel economy, and emissions, we must first understand certain basic concepts of engine design. Following is a brief review of the engine design principles that have had the greatest effect on recent developments in engine design.

FRICTION

Friction is the resistance to movement of two objects that touch each other. Energy is required to overcome this resistance and make one or both of the objects move. Since the automotive engine is full of moving parts that touch one another, some of the engine's energy is used to overcome friction. Therefore, any design change that reduces friction makes more power available to drive the vehicle and makes the engine operate more efficiently.

VOLUMETRIC EFFICIENCY

Volumetric efficiency is the amount of air/fuel mixture that actually enters an engine cylinder compared to the amount that could enter if all conditions were perfect. Therefore, volumetric efficiency is a measure of the engine's ability to pass the air/fuel mixture through the cylinder, to "breathe freely" (Fig. 14). Since an efficient engine performs better, many design changes are intended to increase volumetric efficiency. We will see examples of these types of changes later in this manual.

CONTROL OF COMBUSTION

Lean-Burn and Fast-Burn

Combustion is the process of burning the air/fuel mixture. If it is properly controlled, the combustion process will produce good performance and fuel economy, as well as reduced exhaust emissions. Two terms heard often today are "lean-burn" combustion and "fast-burn" combustion (Fig. 15). Lean-burn combustion uses more air than is required to fully consume the fuel. Fast-burn combustion simply means that burning happens at a faster rate. Fast-burn combustion reduces the amount of heat retained by the combustion chamber and helps make lean-burn combustion possible. Fast-burn combustion also helps reduce the octane requirement of the engine and allow higher compression ratios. Less octane required and higher compression ratios lead to increased fuel economy and better performance. Also, leaner air/fuel mixtures cause fewer hydrocarbon (HC) emissions, and less heat in the combustion chamber reduces the formation of oxides of nitrogen (NO_x). We will see later how changes in such areas as valve and spark plug

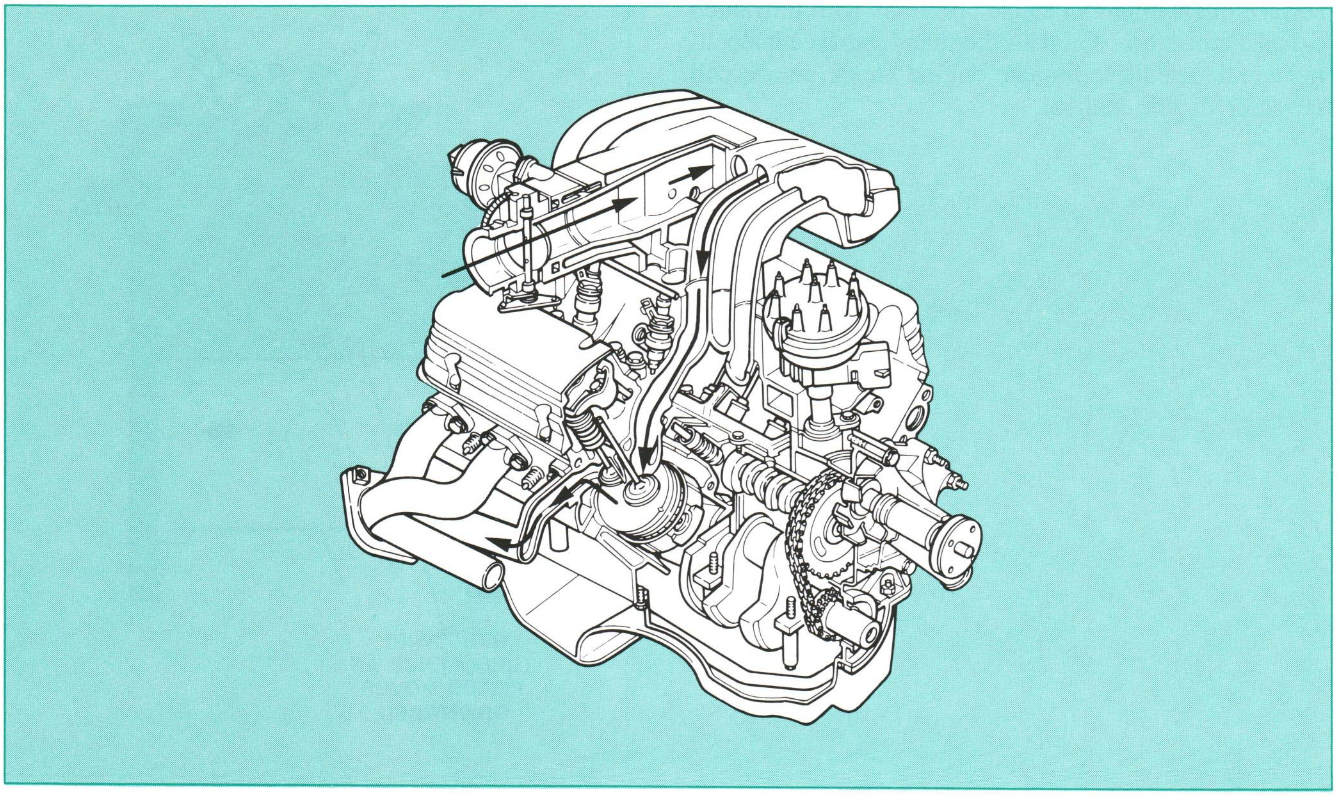


Figure 14 — Volumetric Efficiency

placement, combustion chamber design, and cylinder head design have brought about more efficient combustion in today's engines.

Turbulence and Swirl

If the intake manifold and valve port are properly designed, air is drawn very quickly into the combustion chamber. This fast-moving air stirs the leftover gases from the previous combustion. This rapid movement of gases in the combustion chamber is called turbulence (Fig. 16). In some engines, the combustion chamber is designed to give a winding pattern to the turbulence. This pattern is called swirl (Fig. 16). Increased turbulence and swirl make the air/fuel mixture burn faster and more completely.

Surface Quenching

Surface quenching is a condition that exists in the combustion chamber that does not allow complete combustion of the air/fuel mixture. It occurs when the temperature of the combustion chamber surface is less than the temperature required for good combustion. The temperature of the combustion chamber surface cools the outside of the air/fuel mixture and causes the combustion flame to go out before all of the mixture has finished burning (Fig. 17). This is a major cause of unburned hydrocarbons in the exhaust gas. Therefore, surface quenching can cause problems with unwanted exhaust emissions. On the other hand, surface quenching can be used to eliminate engine knock, as we will see later in this manual.

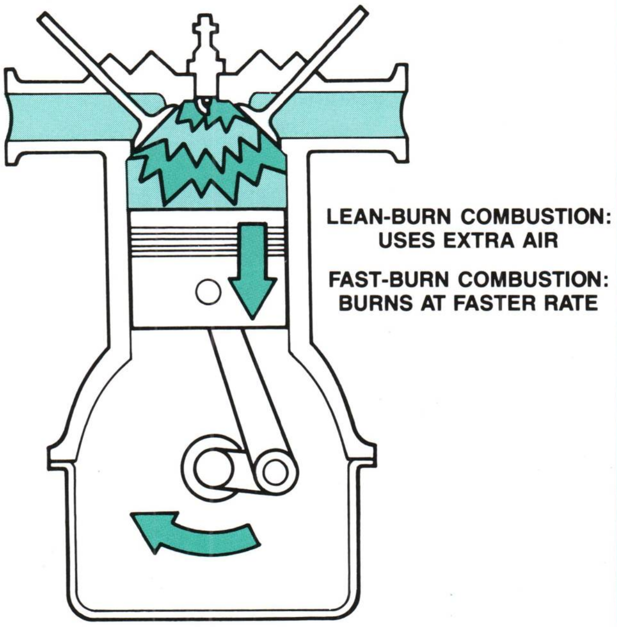


Figure 15 — Lean-Burn and Fast-Burn Combustion

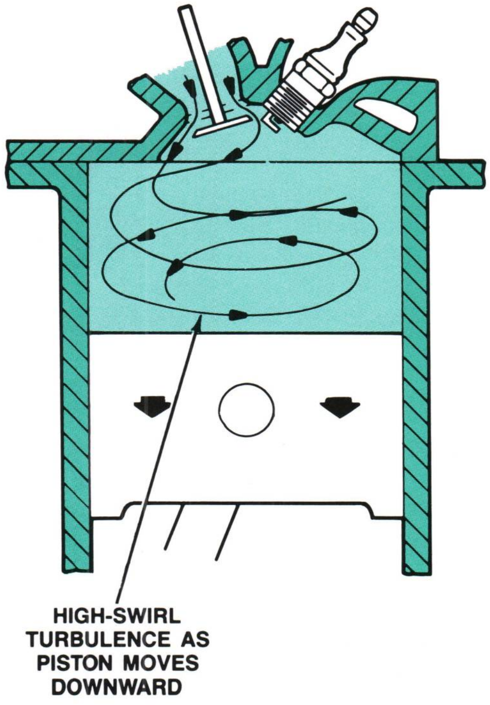


Figure 16 — Turbulence and Swirl

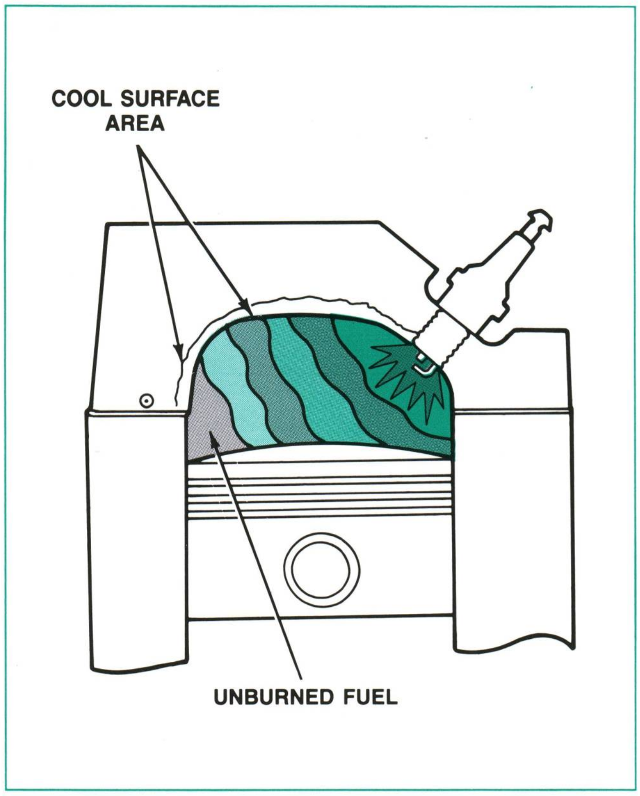


Figure 17 — Surface Quenching

COMPRESSION RATIO

The compression ratio of an engine is a measurement of how much the air/fuel mixture is squeezed or compressed in each cylinder. To figure the compression ratio, divide the air volume of a cylinder with the piston at BDC by the air volume with the piston at TDC (Fig. 18). For example, if the volume with the piston at BDC is 694cc (42.35 in^3) and the volume is 73cc (4.45 in^3) with the piston at TDC, the compression ratio is 694/73 or 9.5:1.

A higher compression ratio increases the thermal efficiency of the engine. This means that with a higher compression ratio, a larger portion of the energy contained in the air/fuel mixture can be used to run the engine. Thus, higher compression ratios can provide better performance and fuel economy (Fig. 19). However, the more the air/fuel mixture is compressed, the hotter it gets. High temperatures in the combustion chamber cause more oxides of nitrogen (NO_x) to form. Also, if the air/fuel mixture gets too hot, it may self-detonate, causing engine knock (Fig. 19). For these reasons, the engine must be designed so that the highest possible compression ratio can be used without knock or too many emissions.

WEIGHT REDUCTION

The automotive engine is a heavy piece of machinery. Reducing the weight of the engine reduces the load the engine has to carry. With a lesser load, more power is available for good performance. Also, less fuel is required to move a lighter load, leading to better fuel economy. In recent years, both new materials and design changes have helped make engines lighter.

STRENGTH

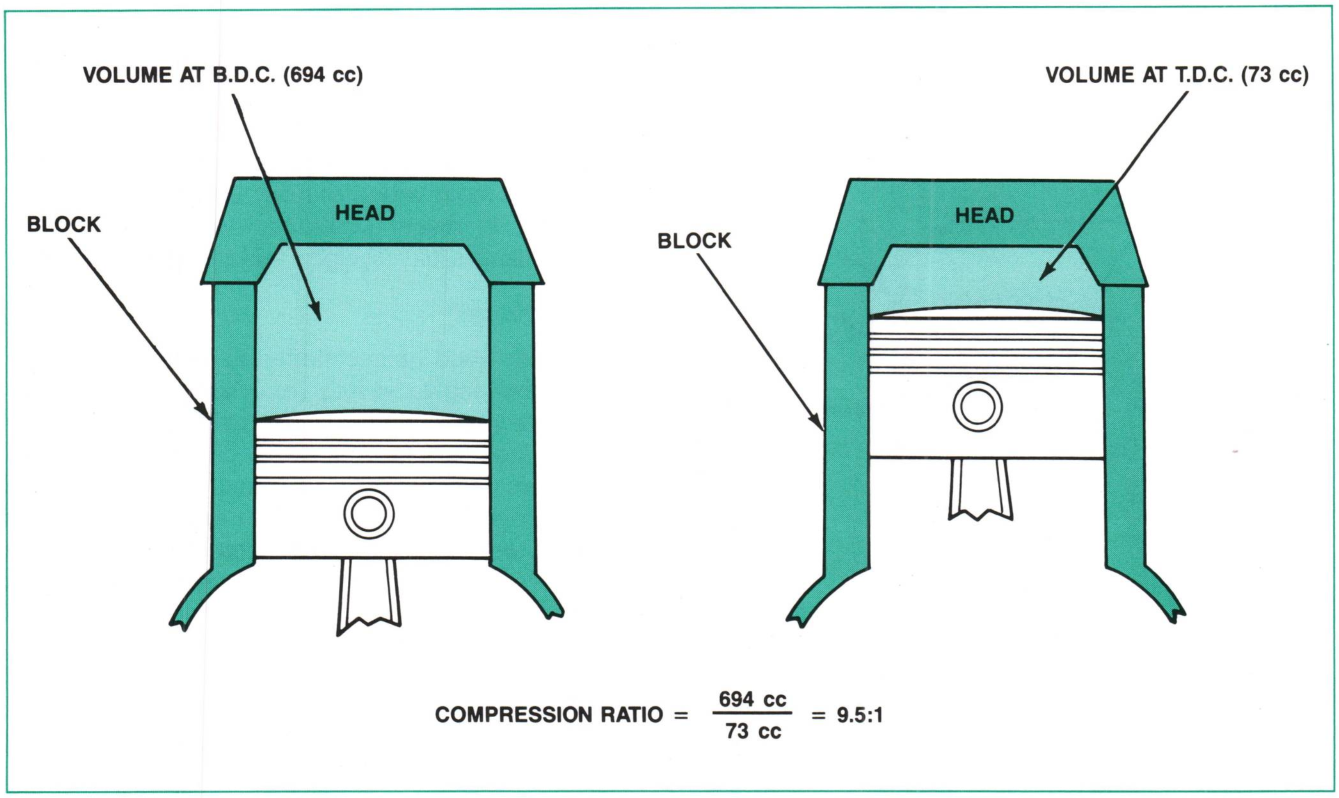
To provide good fuel economy, automobile manufacturers have had to switch from large, eight-cylinder engines to smaller four- and six-cylinder engines. But to offer good performance, these smaller engines must have high compression ratios and must run at high speeds (high RPM). To stand up to this kind of high demand, engine components must be stronger than ever before. The use of both better materials and improved component designs has met the need for strength in today's engines.

BORE/STROKE RATIO

Bore and stroke are two engine measurements that are important to engine design.

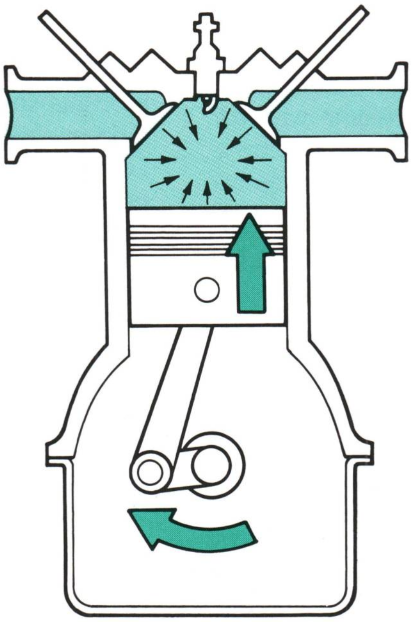
- Bore is the diameter of a cylinder in any engine (Fig. 20).
- Stroke is the distance the piston travels from top dead center to bottom dead center within a cylinder (Fig. 20).

The bore/stroke ratio is the relationship between the bore and stroke of the engine. To find the bore/stroke ratio, divide the bore by the stroke, as shown in Figure 20. If the engine bore is greater than its stroke, the ratio is more than one, and the engine is "oversquare." If the bore and stroke are the same, the ratio is one, and the engine is "square." If the bore is less than the stroke, the ratio is less than one, and the engine is "undersquare." Both the square and oversquare designs can give higher RPM operation ranges and can usually give better economy at low RPM ranges. For this reason, the square and oversquare designs are well-suited to smaller engines that have to provide both performance and economy.


VOLUME AT B.D.C. (694 cc)
VOLUME AT T.D.C. (73 cc)
BLOCK
HEAD
BLOCK
HEAD

$$\text{COMPRESSION RATIO} = \frac{694 \text{ cc}}{73 \text{ cc}} = 9.5:1$$

Figure 18 — Compression Ratio


HIGH COMPRESSION

GOOD FOR
- PERFORMANCE
- FUEL ECONOMY

BAD FOR
- NO_x EMISSIONS
- ENGINE KNOCK

Figure 19 — High Compression: Good and Bad

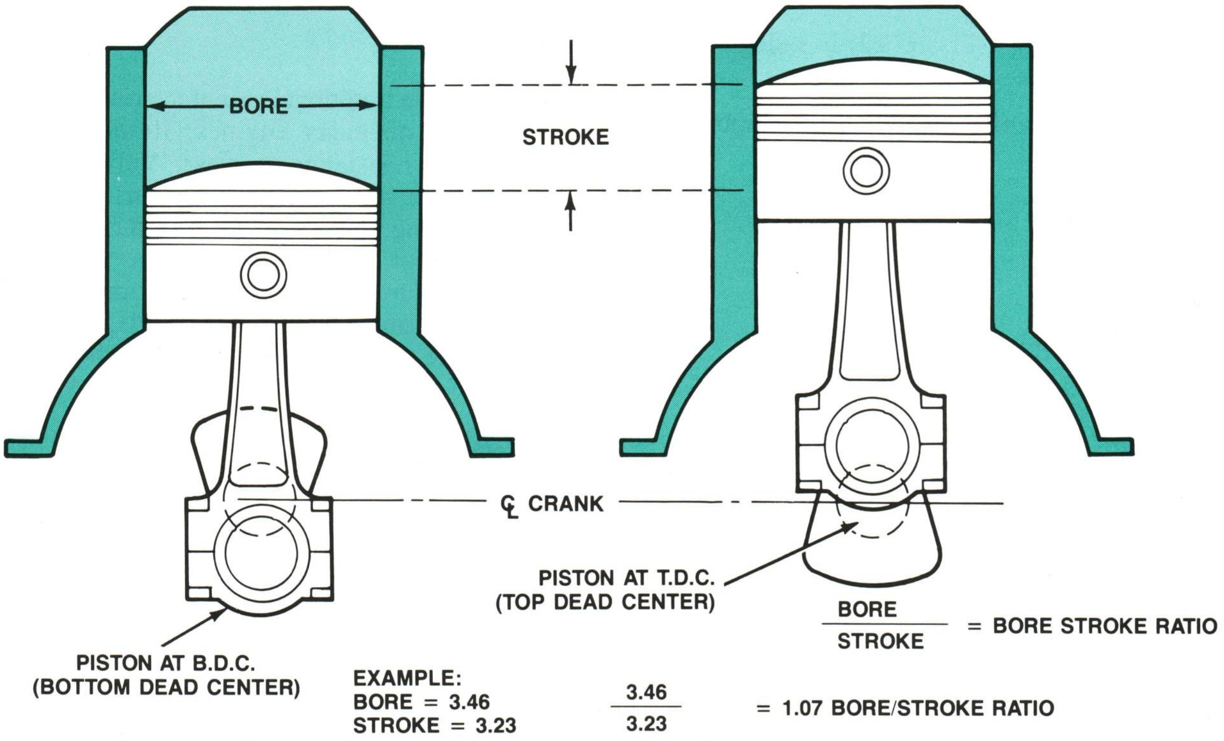

BORE
STROKE
℄ CRANK
PISTON AT T.D.C.
(TOP DEAD CENTER)
PISTON AT B.D.C.
(BOTTOM DEAD CENTER)
BORE / STROKE = BORE STROKE RATIO
EXAMPLE:
BORE = 3.46
STROKE = 3.23
3.46 / 3.23 = 1.07 BORE/STROKE RATIO

Figure 20 — Bore/Stroke Ratio

CYLINDER HEAD/COMBUSTION CHAMBER

CYLINDER HEAD DESCRIPTION

The cylinder head (Figs. 21 and 22) is a single-piece casting that contains:

- The upper portion of each cylinder's combustion chamber
- Valves
- Valve springs
- Valve guides
- Rocker arms or followers
- Valve seating surfaces
- Spark plugs
- Camshaft and supports (overhead cam engines only)

The head includes coolant passages, oil passages, and the intake and exhaust passages at the edge of each combustion chamber. The cylinder head is sealed tightly at the top of the cylinder block with a special gasket. Refer to Figures 21 and 22.

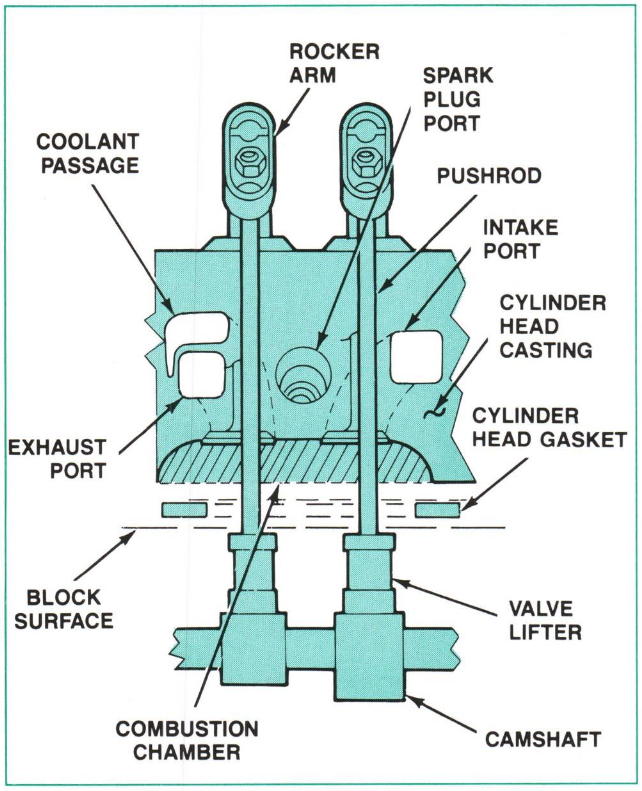

ROCKER ARM
SPARK PLUG PORT
COOLANT PASSAGE
PUSHROD
INTAKE PORT
CYLINDER HEAD CASTING
CYLINDER HEAD GASKET
EXHAUST PORT
BLOCK SURFACE
VALVE LIFTER
COMBUSTION CHAMBER
CAMSHAFT

Figure 21 — Cylinder Head Components — Overhead Valve Design

MATERIALS

Cast Iron

Cast iron is the traditional manufacturing material and is still used on many engines. Its advantages are strength and resistanne to wear. Valve guides and seats and other wear surfaces can be machined directly into the casting, saving on manufacturing costs. The disadvantage of cast iron is that it has greater weight than cast aluminum. However, computer-assisted design and manufacture (CAD/CAM) methods have helped make cast iron heads lighter without a loss of strength.

Cast Aluminum

Cast aluminum is a much lighter material than cast iron. It allows weight reduction of the engine, which helps improve fuel economy. Recent casting technology has made aluminum heads even lighter without a loss of strength and also has reduced the rate of scrappage.

Included in the new casting technology is a process called "lost-foam casting." In lost-foam casting, chunks of styrofoam are glued together to form the shapes of the oil passages, combustion chambers,

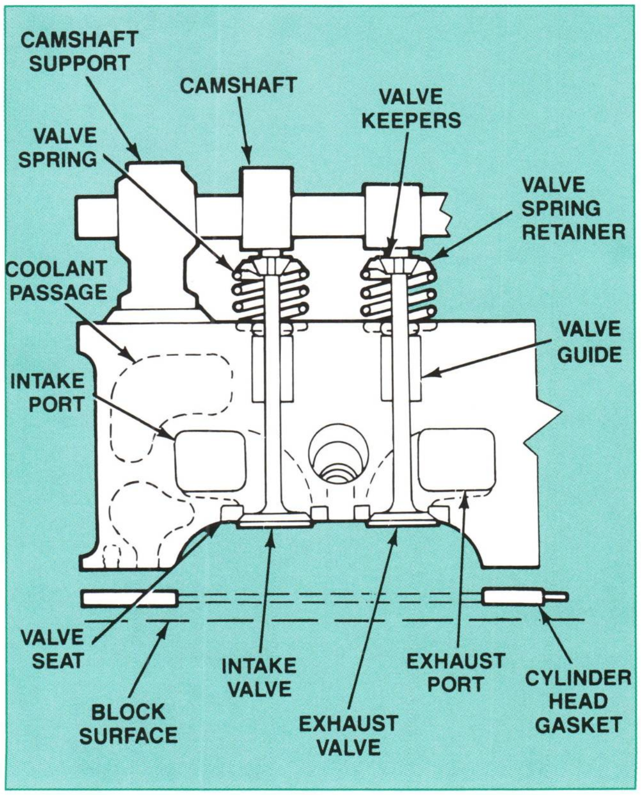

CAMSHAFT SUPPORT
CAMSHAFT
VALVE KEEPERS
VALVE SPRING
VALVE SPRING RETAINER
COOLANT PASSAGE
VALVE GUIDE
INTAKE PORT
VALVE SEAT
INTAKE VALVE
EXHAUST PORT
CYLINDER HEAD GASKET
BLOCK SURFACE
EXHAUST VALVE

Figure 22 — Cylinder Head Components — Overhead Cam Design

ports and oil galleries of a cylinder head. The styrofoam assembly is coated with ceramic and put in a box of sand. When molten aluminum is poured in, the styrofoam vaporizes, and a cylinder head casting is produced. Interestingly, lost-foam casting is based on a process developed by the Chinese hundreds of years ago.

One drawback with cast aluminum is that wear surfaces of the cylinder head, such as the valve guides and seats, require an insert of harder material, since aluminum wears faster than cast iron.

CYLINDER HEAD/COMBUSTION CHAMBER DESIGN

The combustion chamber consists of the piston dome, upper edge of the cylinder wall, and the hollowed out portion of the cylinder head. The design of this chamber is very important, because it helps to determine the engine's fuel economy, performance, and emissions.

The ideal combustion chamber would promote rapid and lean combustion and have high volumetric efficiency, resulting in good performance, good fuel economy, and low emissions. In practice, not all of these things are possible for every engine. There is no such thing as the "perfect" combustion chamber. The design varies with what is wanted from the engine. The factors that must be considered in designing a combustion chamber include the following items. Refer to Figure 23.

- Shape of combustion chamber roof
- Shape of piston dome
- Combustion chamber volume
  - — Less volume means shorter flame travel for faster burn.
- Surface-to-volume ratio
  - — This is the area of the surface of the inside of combustion chamber compared to the volume of the chamber. A large surface-to-volume ratio can interfere with combustion, because heat is lost through the chamber's surface. Heat lost is energy wasted, not used. Also, a large surface-to-volume ratio could cause more surface quenching, resulting in increased hydrocarbon (HC) formation.
- Squish areas
  - — These are the parts of the combustion chamber that are tightly spaced.

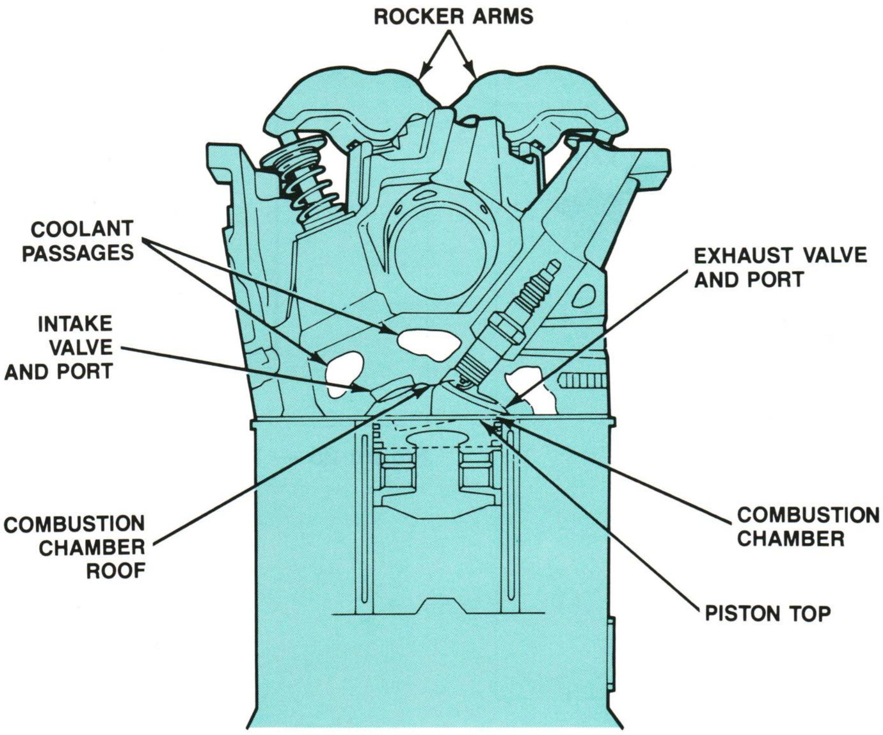


Figure 23 — Cylinder Head and Combustion Chamber — Cross Section

- Shape of intake ports and exhaust ports
- Number of valves
- Compression ratio
- Angle or canting of valves
- Coolant passages
- Oil galleries
- Position of spark plug in combustion chamber

Basic Combustion Chamber Designs

Crossflow Cylinder Head

The crossflow cylinder head (Fig. 24) has intake and exhaust valves/ports positioned on opposite sides of the head from each other. The air/fuel mixture enters the combustion chamber from one side and the exhaust gases pass out the opposite side. The overlap of the intake and exhaust valves — when the exhaust valve stays open for a short period of time during the intake stroke — helps the fuel mixture enter the cylinder while the exhaust gases are purging. This design helps the engine breathe and increases volumetric efficiency on the intake stroke.

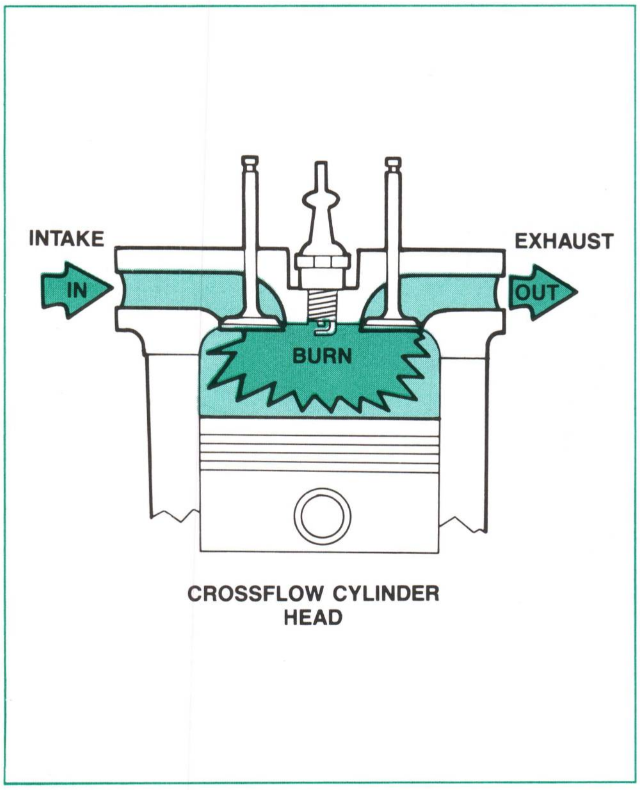


Figure 24 — Crossflow Cylinder Head

Wedge Combustion Chamber

The wedge-shaped combustion chamber (Fig. 25) helps to control the air/fuel mixture burn rate by spreading the ignition charge over the entire surface of the piston. The air/fuel mixture enters the wedge-shaped chamber through an intake valve that is parallel to the exhaust valve. The chamber is formed by an inverted V-shaped piston head and an angled combustion chamber roof. On the compression stroke, the air/fuel mixture is forced into a turbulent area that stirs up and further atomizes the mixture. When the mixture is ignited, the resulting combustion presses down gradually on the piston at first. As the piston is forced away from the upper combustion chamber, the flame spreads evenly — creating a smooth burn with full thrust.

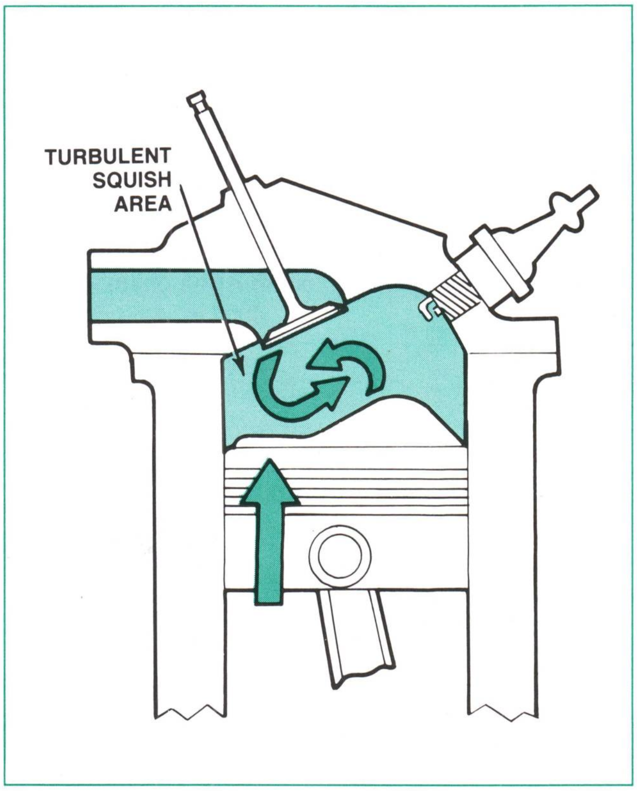


Figure 25 — Wedge-Shaped Combustion Chamber

CYLINDER HEAD/COMBUSTION CHAMBER

Hemispherical Combustion Chamber

The hemispherical combustion chamber (Fig. 26) is a low-turbulence, low-swirl chamber that centers the air/fuel mixture near the spark plug for even spreading of the combustion flame. The hemispherical shape allows the use of bigger valves. Bigger valves increase volumetric efficiency, making the hemispherical chamber ideal for high-performance engines. On the other hand, the air/fuel mixture burns slowly compared to a wedge-shaped or high-swirl combustion chamber, so the hemispherical chamber may have problems with engine knock with lower octane fuel.

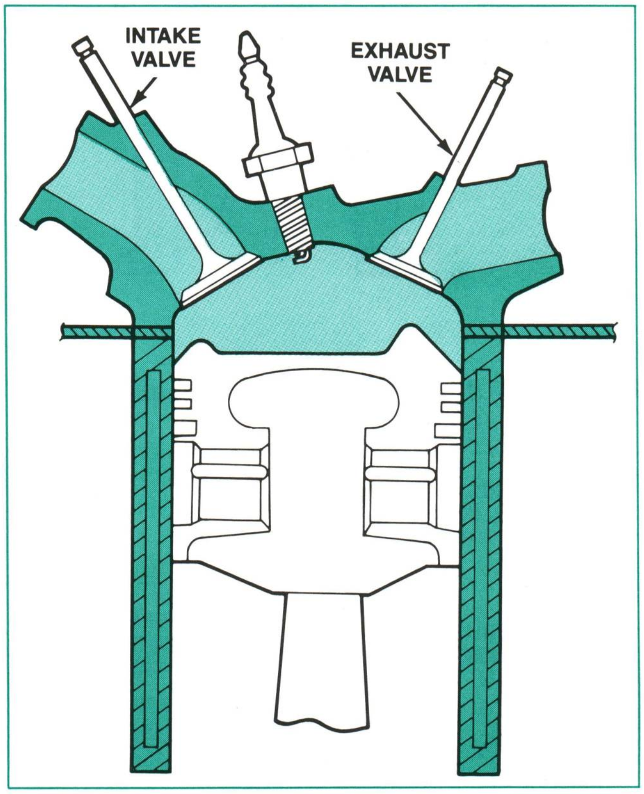


Figure 26 — Hemispheric Combustion Chamber

Pent-Roof Combustion Chamber

The pent-roof combustion chamber is shaped like a slightly rounded, inverted "V" (Fig. 27). The two planes of the V make the pent-roof chamber ideal for a four-valve-per-cylinder design (although four valves are not required). A domed piston was often used in the past to create a crescent shape (Fig. 27) for greater squish and turbulence, as well as higher compression. However, current designs use a flat top or dished piston for faster burn and greater efficiency.

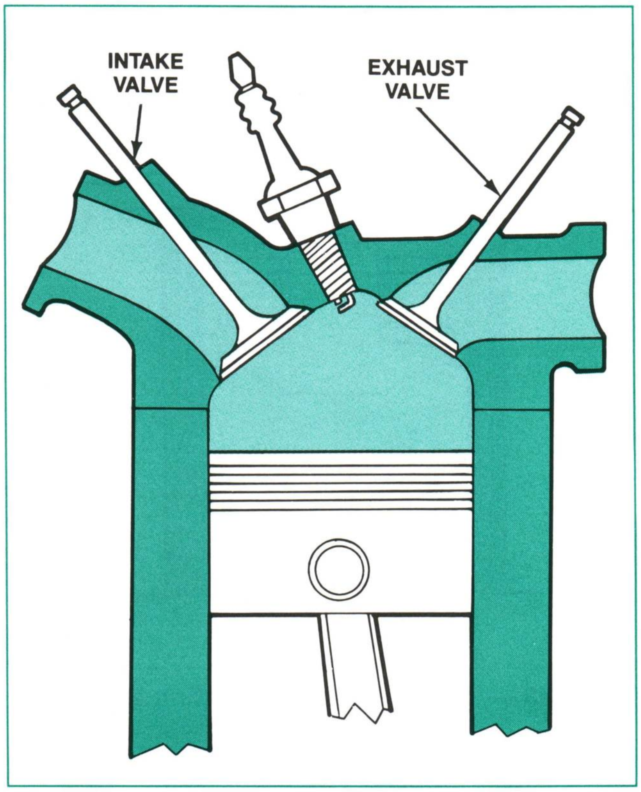


Figure 27 — Pent-Roof Combustion Chamber

Dual Squish Combustion Chamber

In this combustion chamber design, the chamber is narrowed at two sides (Fig. 28). On the compression stroke, the piston squeezes the air-fuel mixture out of the squish areas, stirring the mixture up for increased turbulence and more efficient combustion.

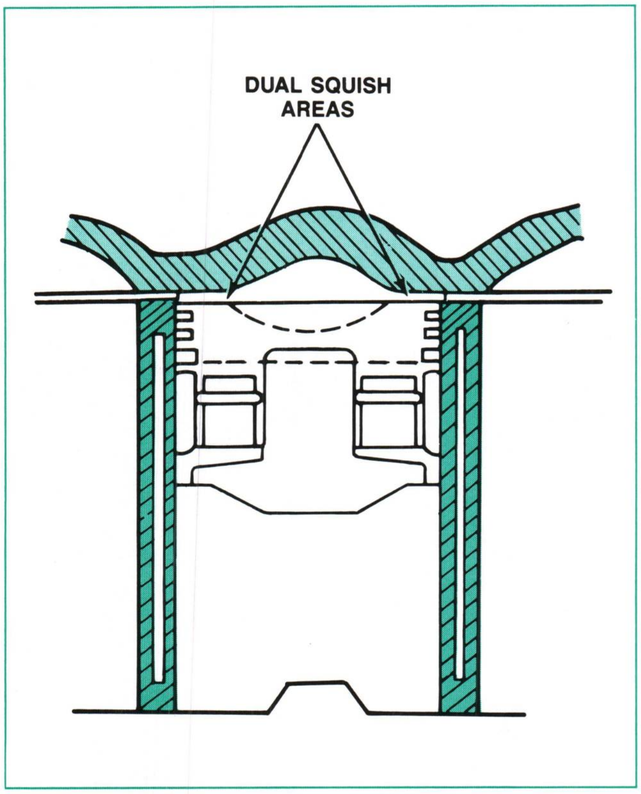

DUAL SQUISH AREAS

Figure 28 — Dual Squish Combustion Chamber

Stratified Charge Combustion Chamber

The stratified charge combustion chamber uses an extra intake valve to provide turbulence and a richer mixture, which is added to a small pre-combustion area near the spark plug. When this richer mixture is added to the pre-combustion chamber, it stirs up the lean air/fuel mixture and combines the rich and lean layers of mixture. The lean layers burn quickly along with the rich layers, which makes the process very fuel-efficient. Several variations of this design are in use today (Figs. 29 and 30).

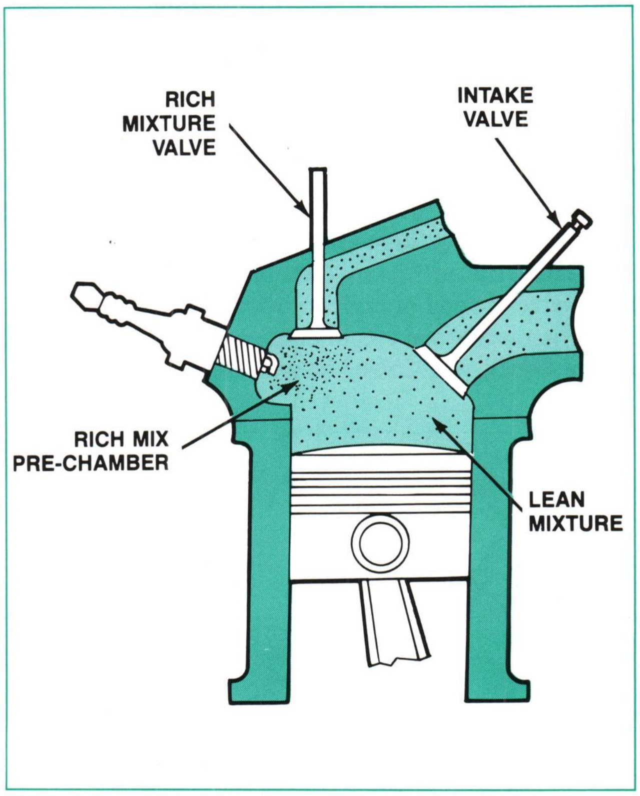

RICH MIXTURE VALVE
INTAKE VALVE
RICH MIX PRE-CHAMBER
LEAN MIXTURE

Figure 29 — Stratified Charge Combustion Chamber

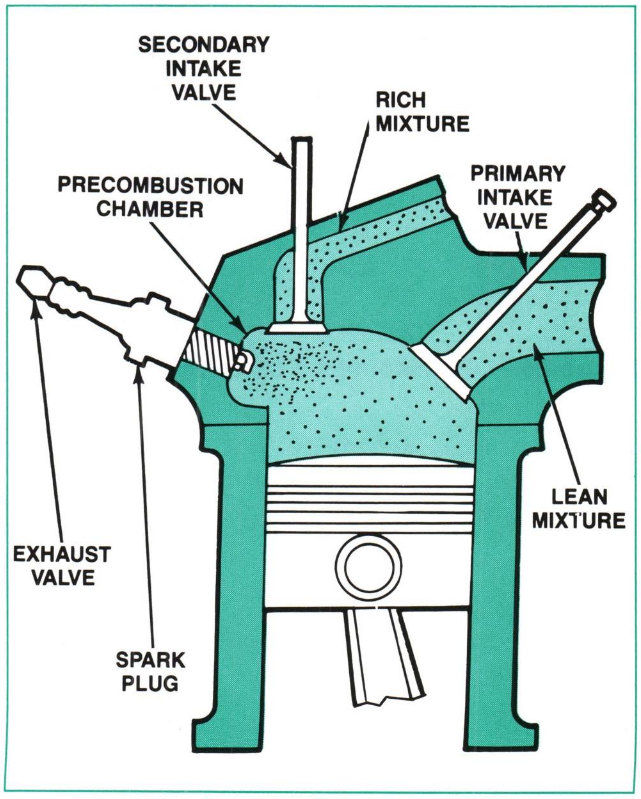

SECONDARY INTAKE VALVE
RICH MIXTURE
PRECOMBUSTION CHAMBER
PRIMARY INTAKE VALVE
LEAN MIXTURE
EXHAUST VALVE
SPARK PLUG

Figure 30 — Honda CVCC Stratified Charge Combustion Chamber

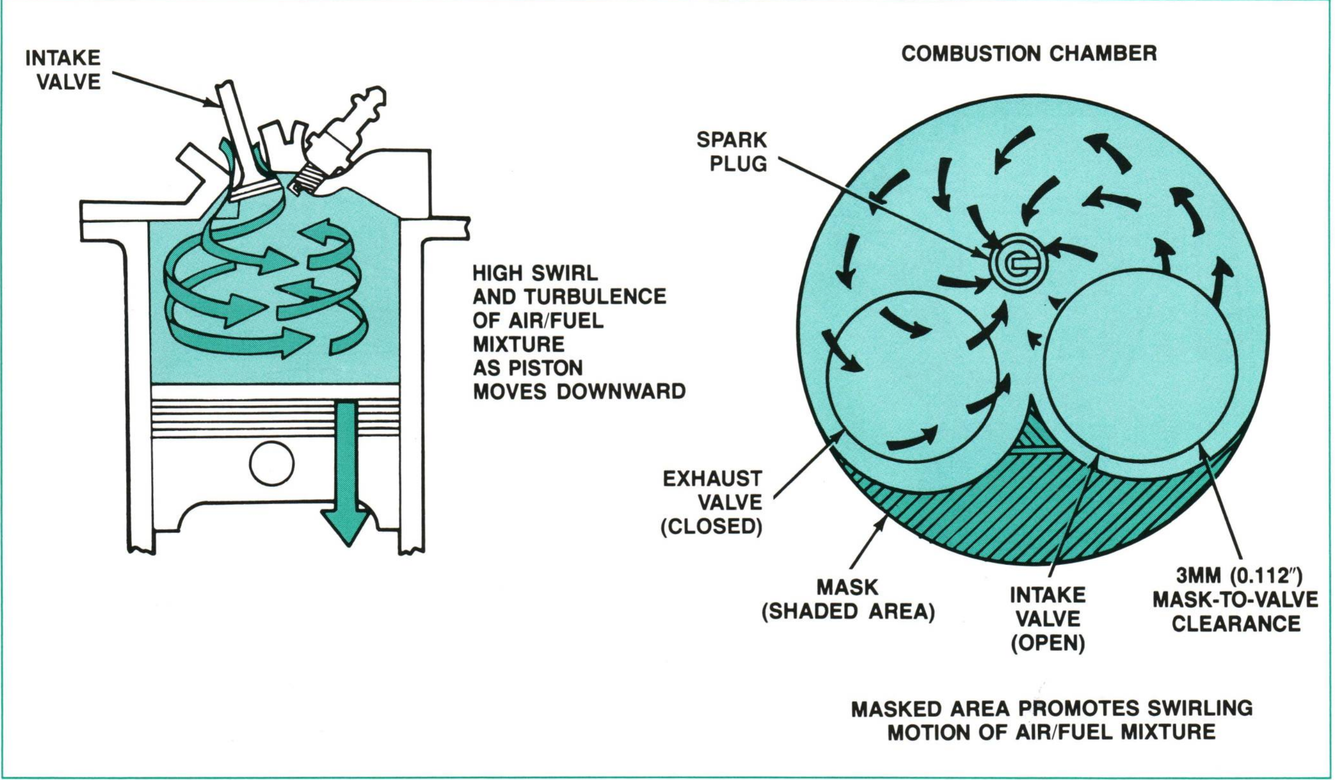

INTAKE VALVE
HIGH SWIRL AND TURBULENCE OF AIR/FUEL MIXTURE AS PISTON MOVES DOWNWARD
COMBUSTION CHAMBER
SPARK PLUG
EXHAUST VALVE (CLOSED)
MASK (SHADED AREA)
INTAKE VALVE (OPEN)
3MM (0.112″) MASK-TO-VALVE CLEARANCE
MASKED AREA PROMOTES SWIRLING MOTION OF AIR/FUEL MIXTURE

Figure 31 — High Swirl Combustion Chamber Masking

High Swirl Combustion Chamber

The high swirl combustion chamber (Fig. 31) uses the shaping of the intake port or the area around the valves to direct the air/fuel mixture so that it is more thoroughly mixed. By masking an area around the valves, there is a higher rate of swirl and turbulence that creates a fast burn condition in the combustion chamber. The combustion chamber is often smaller than most other designs. The small chamber, used with flat pistons and centrally-located spark plugs, keeps the flame travel short and combustion quick. The compression ratio is higher to compress the well-mixed air/fuel mixture, and a tuned or bifurcated (two-to-one channel) exhaust helps to purge the exhaust gases for better engine breathing and performance. Combustion is more efficient and emissions are kept to a minimum.

Four-Valve Combustion Chamber

The four-valve combustion chamber (Fig. 32) is a design that is being used more and more today, particularly for high-performance engines. The four-valve design has several advantages:

- With four valves, each valve can be smaller and lighter.
- The total "curtain" area (the passage between the open valve and its seat) is larger, providing better volumetric efficiency.
- With two intake passages, the cylinder can fill better with lower valve lifts.
- Since more air enters faster through the two intake ports, duration and overlap can be decreased without a loss of power.
- The design is well-suited to a centrally-mounted spark plug (whose advantages will be discussed shortly).

All of these advantages add up to increased peak horsepower potential and more torque over a wider range of engine speeds.

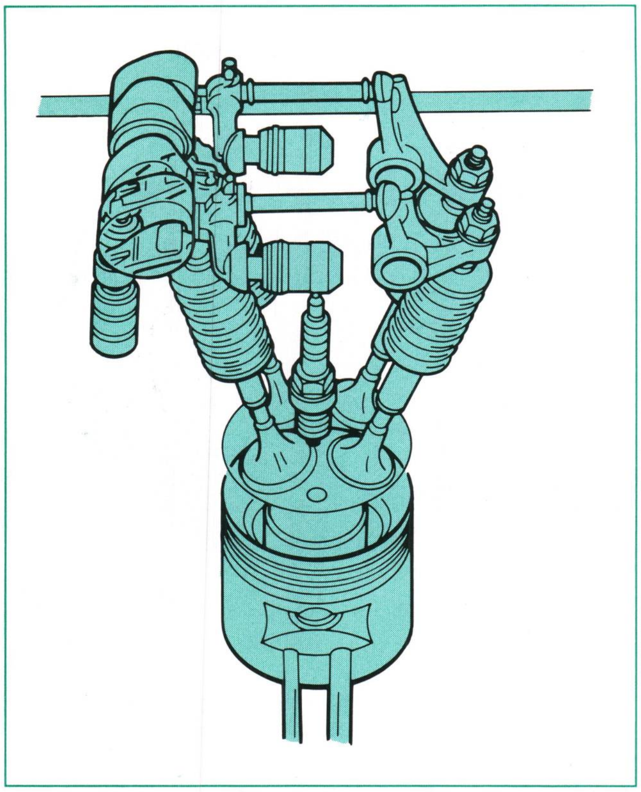


Figure 32 — Four-Valve Combustion Chamber

Other Design Considerations

Spark Plug Placement

One design feature that works well for almost every combustion chamber design is the center-mounted spark plug (Fig. 33). The closer the plug is to the center of the chamber, the shorter is the flame travel to all parts of the chamber. Lower placement of the spark plug gap near the center of the clearance volume can also help reduce flame travel. Some manufacturers have used an extended reach plug (Fig. 34) that is placed deeper in the chamber to bring the gap closer to the center of the charge. When the combustion is started from the center of the chamber rather than from the side, there is less flame travel and the combustion is quicker and more complete.

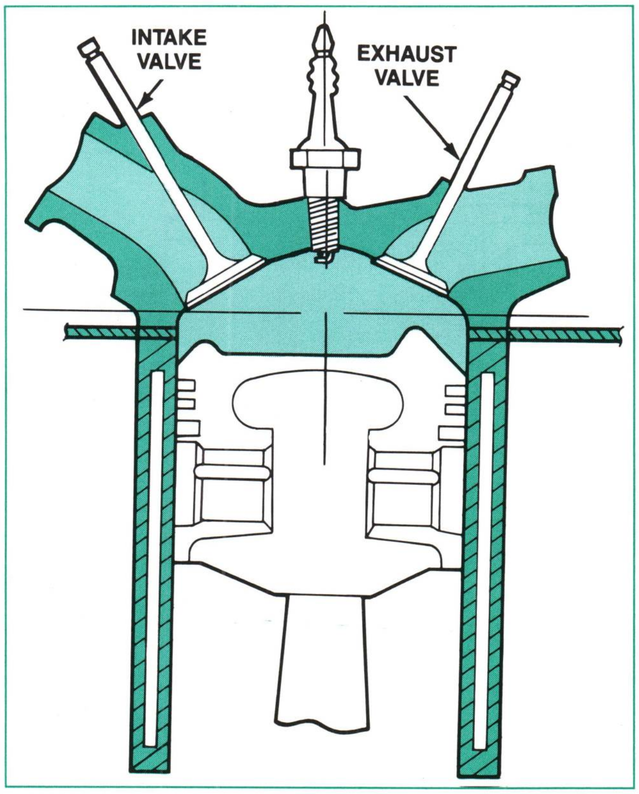

INTAKE VALVE
EXHAUST VALVE

Figure 33 — Center-Mounted Spark Plug

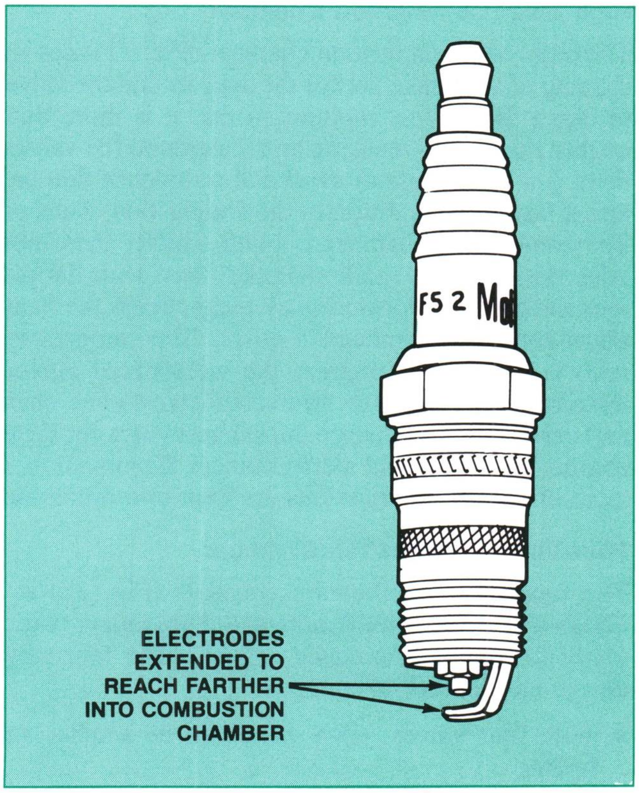

FS 2 Mo
ELECTRODES EXTENDED TO REACH FARTHER INTO COMBUSTION CHAMBER

Figure 34 — Extended Reach Spark Plug

CYLINDER HEAD/COMBUSTION CHAMBER

Valve Angle or Canting

In order to maximize the output of an engine, some automakers have relied on an important method of angling the valve, known as canting (Fig. 35). The angling of the valve in the head is often done to take advantage of an intake or exhaust passage design. The advantages of canting may include:

- A knock-resistant combustion chamber
- Control of turbulence and/or swirl in the combustion chamber
- More compact combustion chamber

Recessed Valves

On some vehicles, the combustion chamber design allows the valves to be recessed, or placed deeper in the head (Fig. 36). This method is sometimes used with masking, which causes the incoming air/fuel mixture to swirl even more rapidly for a fast burn of the fuel. This reduces the octane requirement of the engine, and allows higher compression ratios to be used (for fuel economy) without excessive temperature-related problems.

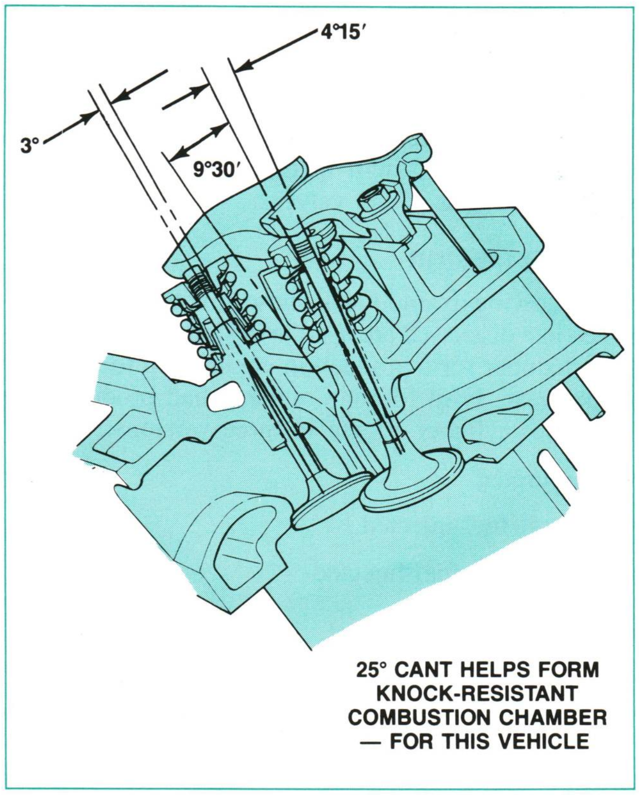

4°15′
3°
9°30′
25° CANT HELPS FORM KNOCK-RESISTANT COMBUSTION CHAMBER — FOR THIS VEHICLE

Figure 35 — Valve Canting

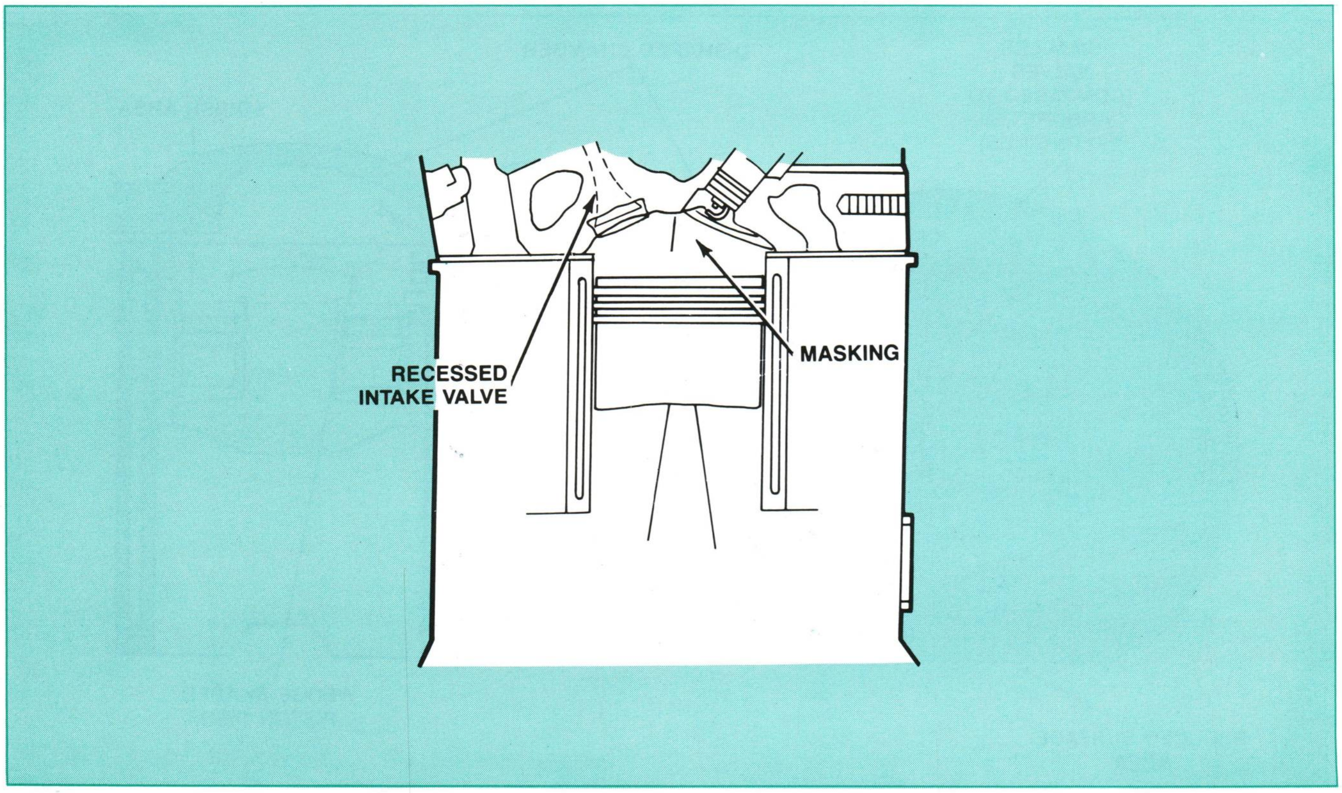

RECESSED INTAKE VALVE
MASKING

Figure 36 — Valve Recessing

CYLINDER HEAD/COMBUSTION CHAMBER

Intake Port Shaping

The shape of the intake port can affect how the intake air flows into the combustion chamber. For example, the port can be designed to wrap around the valve (Fig. 37), causing swirl in the combustion chamber without masking of the valves.

Sample Design

The following example will show how the design principles just discussed are used in designing the combustion chamber for a production engine. Up to the 1987 model year, Ford Motor Company had produced the 1.9L four-cylinder engine in three versions:

- Carbureted
- Central fuel-injected
- Multi-point fuel-injected

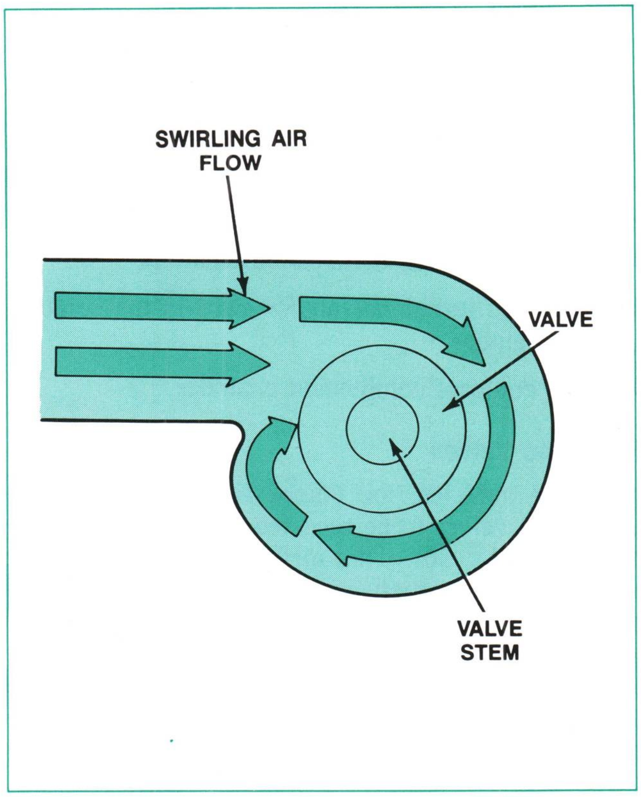

SWIRLING AIR FLOW
VALVE
VALVE STEM

Figure 37 — Swirl Intake Port

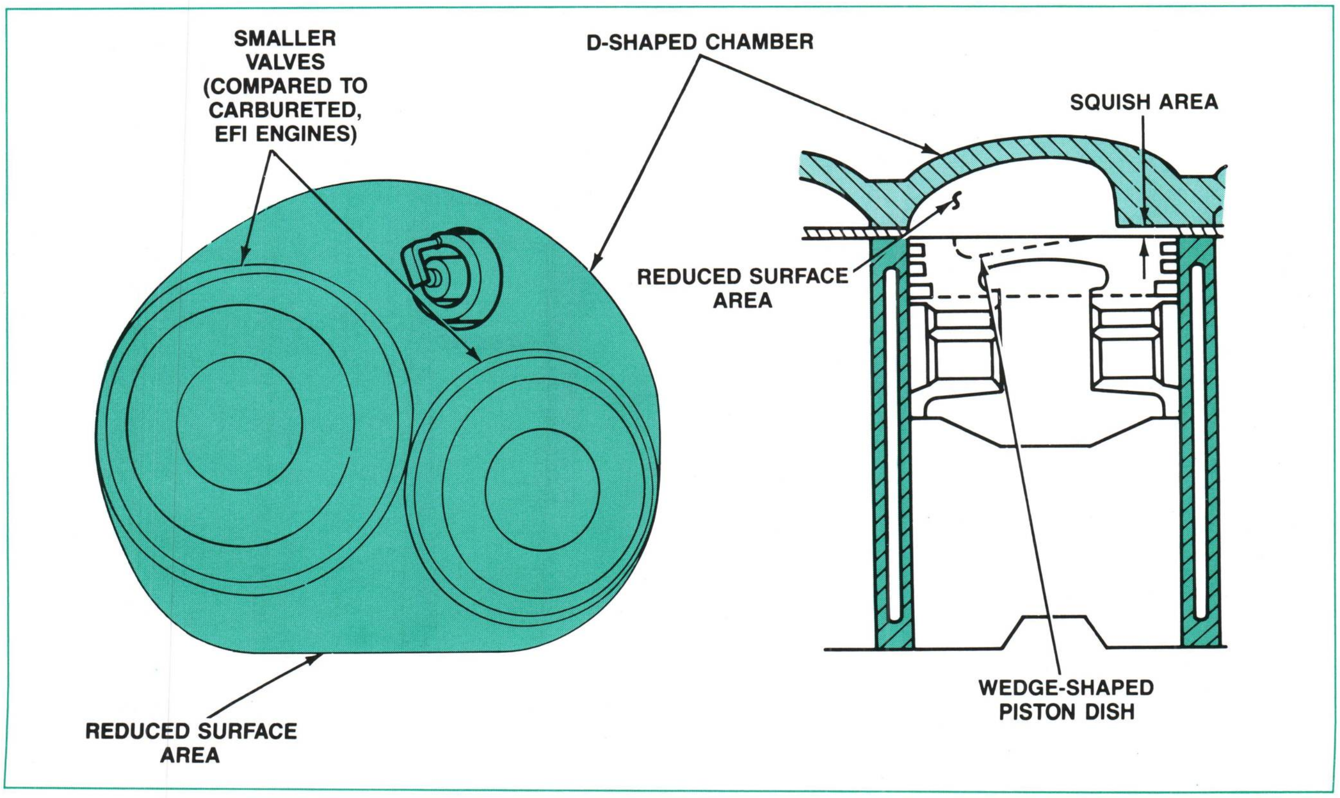

SMALLER VALVES (COMPARED TO CARBURETED, EFI ENGINES)
D-SHAPED CHAMBER
SQUISH AREA
REDUCED SURFACE AREA
WEDGE-SHAPED PISTON DISH
REDUCED SURFACE AREA

Figure 38 — 1987 1.9L Central Fuel-Injected Engine Combustion Chamber

CYLINDER HEAD/COMBUSTION CHAMBER

The combustion chambers for these three versions of the same basic engine are quite different. Here is why.

1.9L Carbureted Engine

The carbureted 1.9L engine had a high-swirl combustion chamber much like the one described earlier in this section. The valves were masked, the intake port was a fairly straight passage, and the piston was flat-topped with fly cuts (Fig. 31). This design provided acceptable performance and fuel economy.

1.9L Central Fuel-Injected Engine

While the carbureted version performed well enough, design engineers felt that the 1.9L engine could be improved by adding central fuel injection and redesigning the combustion chamber. The revised combustion chamber was to have less surface area for a better surface-to-volume ratio. Less surface area meant that the valves had to shrink (Fig. 38). Smaller valves with masking would have meant less volumetric efficiency, since masking slows the intake airflow somewhat. Therefore, the masking was removed and the intake port was redesigned. The new intake port's shape makes the air/fuel mixture flow around the valve, creating swirl (Fig. 37).

The combustion chamber's shape was also revised to a D-shape (Fig. 38). This shape causes squish on the flat side and shortens flame front travel. However, the D-shape chamber was smaller, so something had to be done to restore volume so that the compression ratio would remain the same (9.0:1) to prevent knocking. The answer was to add a wedge-shaped dish to the piston (Fig. 38). The dish added the needed volume and centered the volume under the spark plug. The result of these design changes is more efficient combustion, proven by improved fuel economy, with no loss of performance.

1.9L Multi-Point Fuel-Injected Engine

The multi-point fuel-injected 1.9L engine is designed to emphasize performance over fuel economy, so its combustion chamber is quite different from the other versions. It is a hemispherical chamber like the one discussed earlier in this section. The only turbulence is provided by the dual squish effect of the dished dome piston as it rises on the compression stroke (Fig. 39). Reduced turbulence and the uncentered spark plug make combustion in this chamber somewhat less efficient than in the central fuel-injected 1.9L engine. However, the valves are larger. In addition, the cam provides higher valve lift and longer duration, and the tuned intake manifold rams more air/fuel mixture into the chamber. The result of these differences is poorer fuel economy, but much better performance than the other versions of the 1.9L engine.

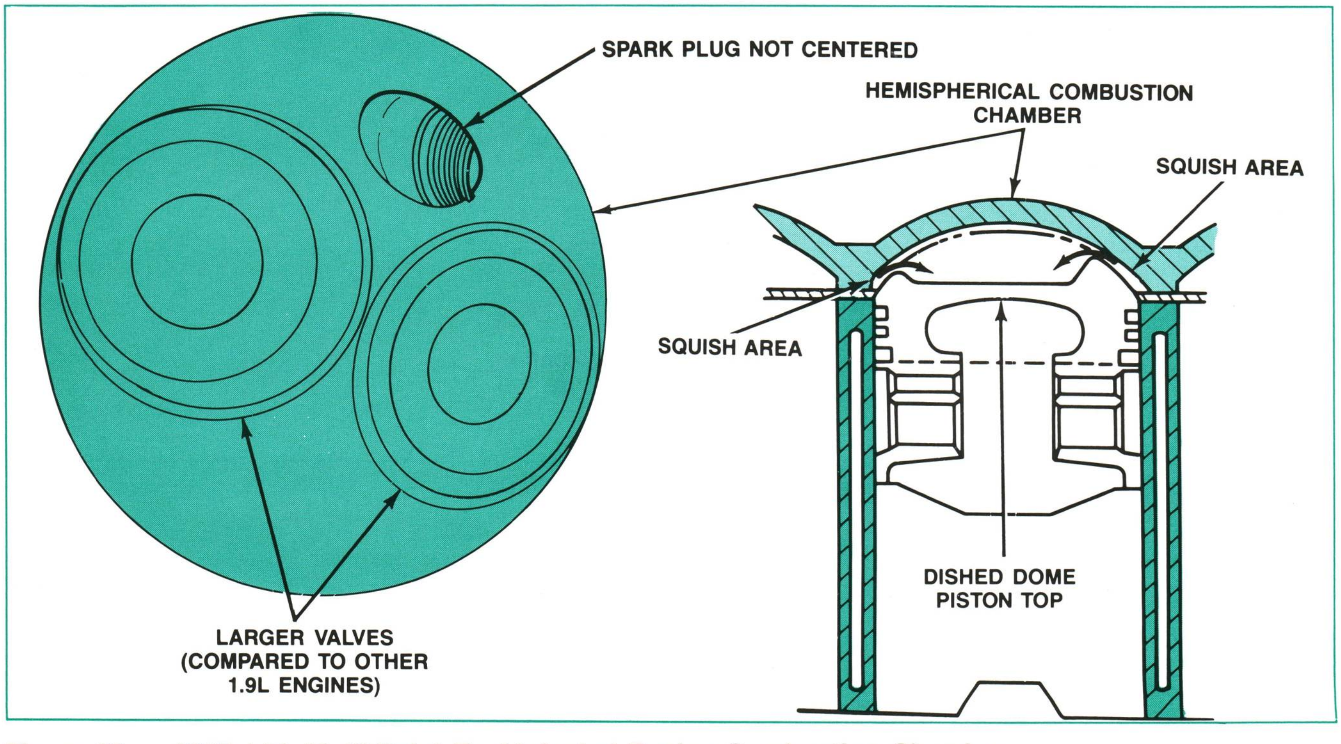

SPARK PLUG NOT CENTERED
HEMISPHERICAL COMBUSTION CHAMBER
SQUISH AREA
SQUISH AREA
DISHED DOME PISTON TOP
LARGER VALVES (COMPARED TO OTHER 1.9L ENGINES)

Figure 39 — 1987 1.9L Multi-Point Fuel-Injected Engine Combustion Chamber

PISTONS

DESCRIPTION

The piston forms the bottom surface of the combustion chamber. The force of the expanding air/fuel mixture at the time of ignition presses on the top of the piston, driving the piston down in the cylinder. The force applied to the piston is very great, so the piston must be very strong. On the other hand, it must be fairly lightweight for fuel economy and performance reasons.

Below the top of the piston are a series of grooves called the ring lands (Fig. 40). These grooves are used to contain the piston rings. Below the ring lands is a bore or hole which is used for the piston pin, sometimes called the wrist pin. The pin connects the piston to the connecting rod.

The area below the piston pin is called the skirt (Fig. 40).

The connecting rod (Fig. 40) transmits the pressure applied to the piston to the crankshaft. The crankshaft end of the connecting rod is made in two pieces. The upper half is part of the rod. The lower half is called the rod cap and is bolted to the rod.

Piston rings are used to fill the necessary expansion gap between the piston and cylinder wall. Piston rings serve four major functions:

- Seal combustion chamber at piston.
- Help lubricate cylinder walls.
- Remove oil from cylinder walls so that it is not burned in combustion.
- Carry heat from piston to cylinder walls to help cool piston.

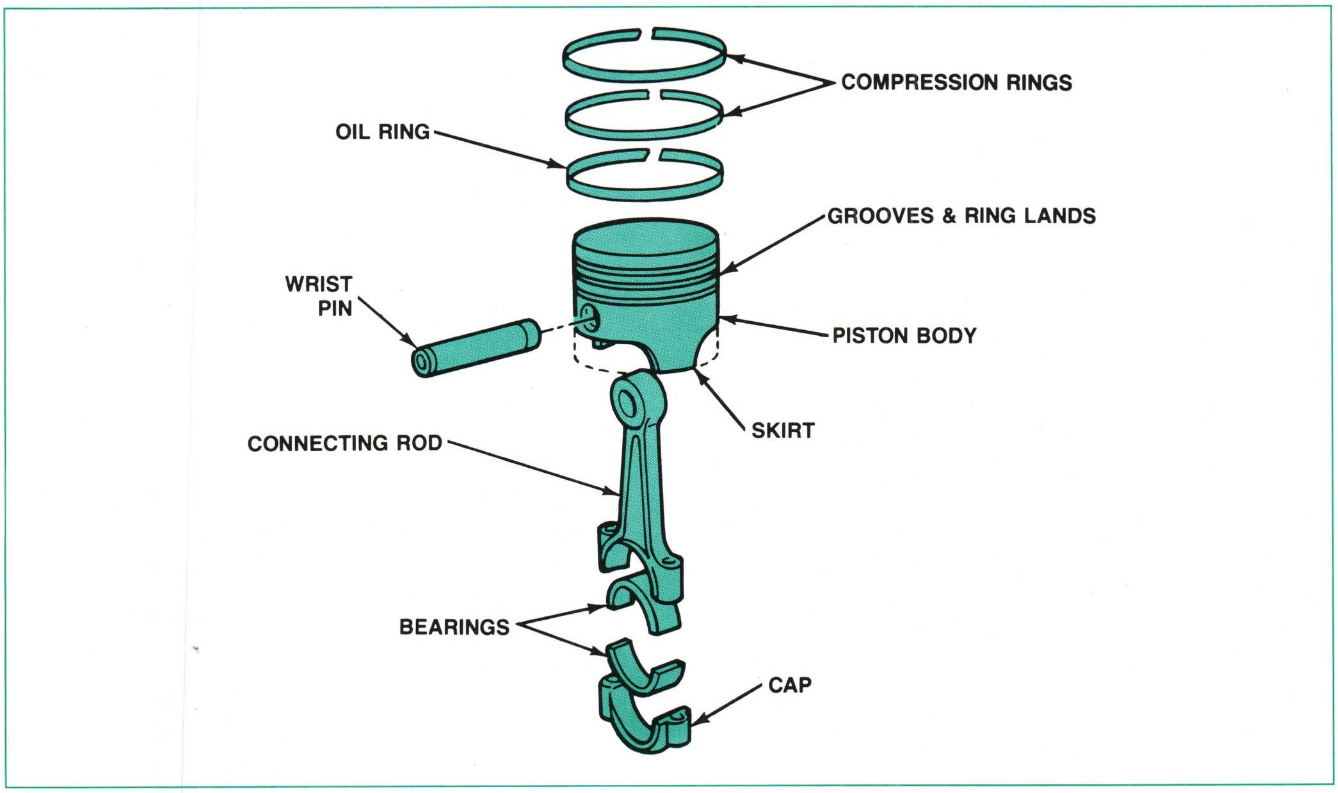


Figure 40 — Piston and Connecting Rod

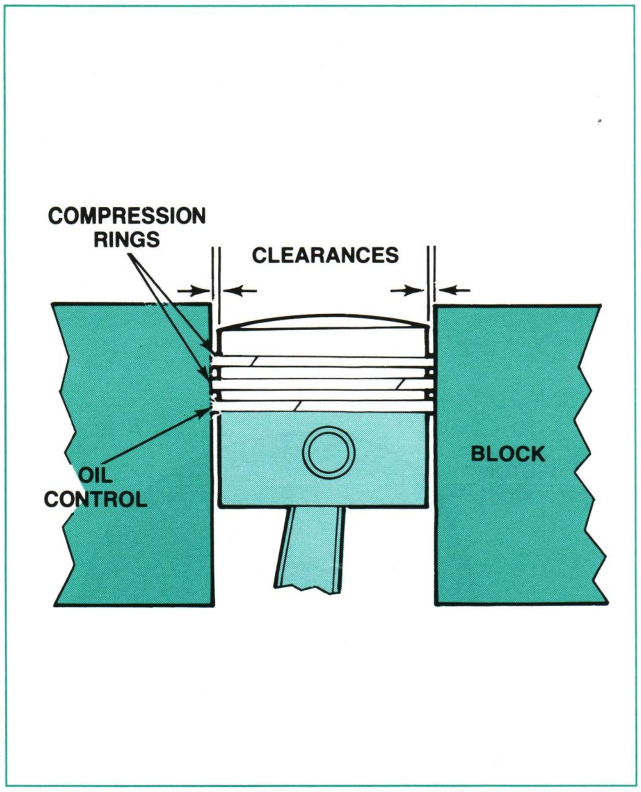


Figure 41 — Piston Rings

In most engines, the top two rings are the compression rings, while the bottom ring is the oil control ring (Fig. 41).

The primary job of the compression rings is to form the seal between the piston and cylinder walls. Combustion pressure forces the rings against the cylinder wall and against the bottom of the ring groove (Fig. 42). The compression rings also remove oil from the cylinder walls and conduct heat away from the piston.

The oil control rings both lubricate and remove excess oil from the cylinder walls. The oil control ring is slotted so that oil can pass through it in both directions. Excess oil passes through slots in the piston and returns to the oil sump through the open section of the piston.

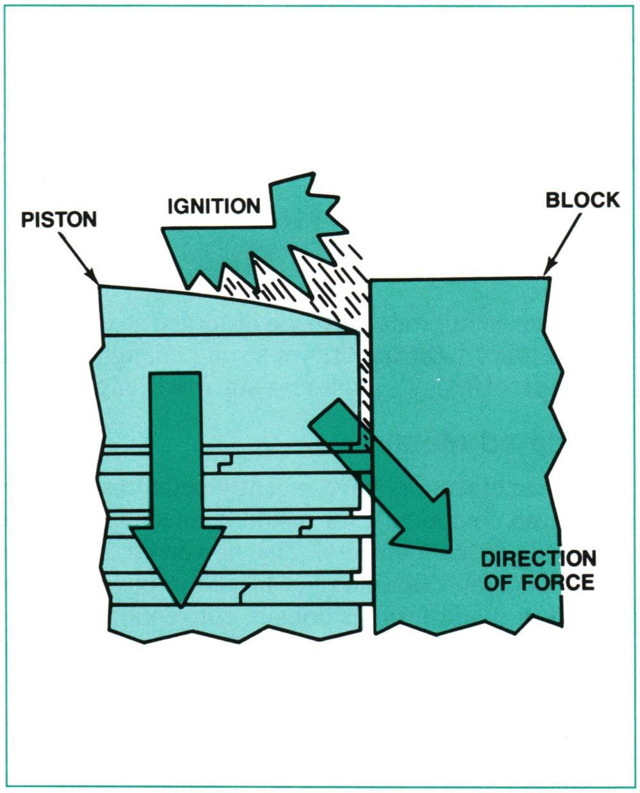


Figure 42 — Operation of Compression Rings

PISTON MATERIALS

Cast Iron

Cast iron was used extensively in the past. However, it is too heavy for modern engines and is almost never used today.

Aluminum

Aluminum is the material most used for pistons in today's gasoline engines. It is lighter than cast iron, and modern manufacturing processes make it strong enough to stand up to combustion pressure. For example, forged aluminum offers durability and resistance to stress for engines that run at higher RPMs.

Cast aluminum, on the other hand, has a tendency to lose its strength at higher RPMs. With cast aluminum pistons, a high-strength steel insert is often added to help the cast material retain the proper rigidity at higher operating speeds, which helps to control a piston's thermal expansion during combustion.

Aluminum Alloys

Some pistons today are being made of aluminum alloys. For example, an aluminum alloy containing a lot of silicon is lighter and resists wear better than aluminum alone.

CONNECTING ROD MATERIALS

Steel

Most connecting rods are made of forged steel. Forged steel is fairly lightweight, yet strong enough to stand the stress of today's high-revving small engines.

Powdered Metal

Some manufacturers have recently begun using powdered iron compounds for piston connecting rods and other engine components. The powdered iron compound is compressed and hot forged in powder form, instead of liquid form as done in conventional casting and forging. The finished part is then denser, stronger, and lighter than a cast or forged part.

RING MATERIALS

Rings are usually made of a high-strength steel that is coated with a chromium or molybdenum finish for better resistance to wear. Some newer ring material alloys have been used to reduce friction against the cylinder wall, without a loss of sealing ability. This happens because the memory (the material's ability to return to its original shape) of the newer materials is much better than that of materials used before. The improved memory allows the ring to seal without applying as much pressure to the cylinder wall. The reduced pressure, in turn, reduces friction.

DESIGN

Since the piston top forms the bottom of the combustion chamber, the piston must be designed to help make combustion more efficient. The shape of the piston must fit in with the design of the rest of the combustion chamber so that the air/fuel mixture burns quickly and efficiently, producing as much power as possible. The three major piston designs are:

- Dished
- Flat-topped
- Domed

These three basic designs can be adjusted in many ways to help form the best combustion chamber design for an individual engine. A few examples follow.

Dished Pistons

A dished piston has an indentation in the top that is shaped like a dish (Fig. 43). Dishing the piston is an easy way to add volume to the combustion chamber (Fig. 44). Volume may have to be added to reduce the compression ratio or to make up for volume lost when the cylinder head is redesigned.

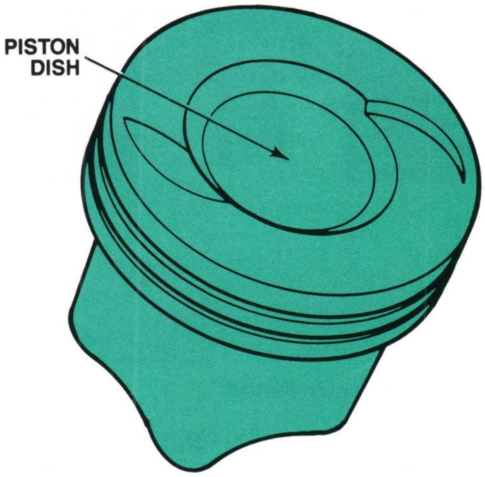


Figure 43 — Dished Piston Top

Some engines use a wedge-shaped dish in the pistons (Fig. 45). In combination with the shape of the cylinder head, the wedge-shaped dish centers the combustion chamber volume, keeping the air/fuel mixture closer to the spark plug for faster burn.

Flat-Topped Pistons

The flat top is the simplest piston design. It is also the easiest to cool and has less surface area than dished or domed designs. Less piston surface area reduces the overall surface area of the combustion chamber, which can make combustion more efficient in some cases.

Domed Pistons

Just as a piston dish can add volume to the combustion chamber, a dome can reduce volume (Fig. 46). The use of domed pistons tends to raise the compression ratio, which can increase performance and improve

PISTONS

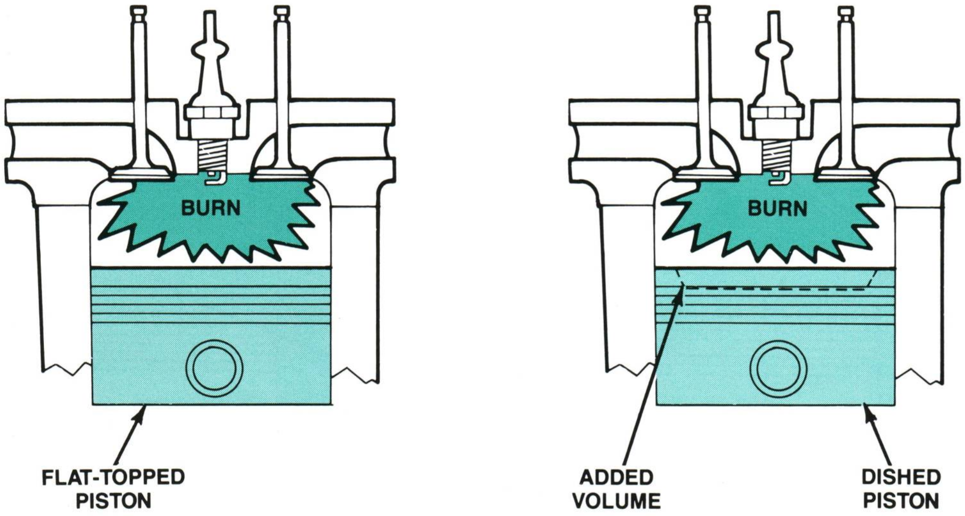

BURN
FLAT-TOPPED PISTON
BURN
ADDED VOLUME
DISHED PISTON

Figure 44 — Increased Combustion Chamber Volume with Dished Piston Top

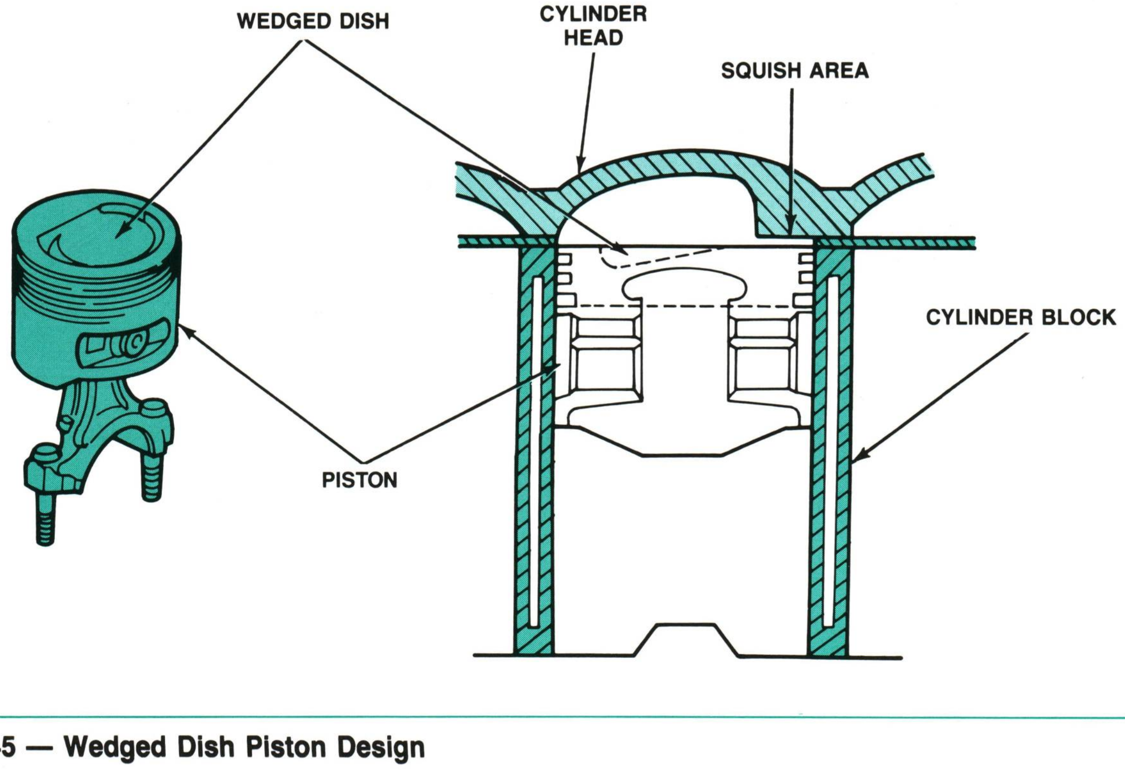

WEDGED DISH
CYLINDER HEAD
SQUISH AREA
CYLINDER BLOCK
PISTON

Figure 45 — Wedged Dish Piston Design

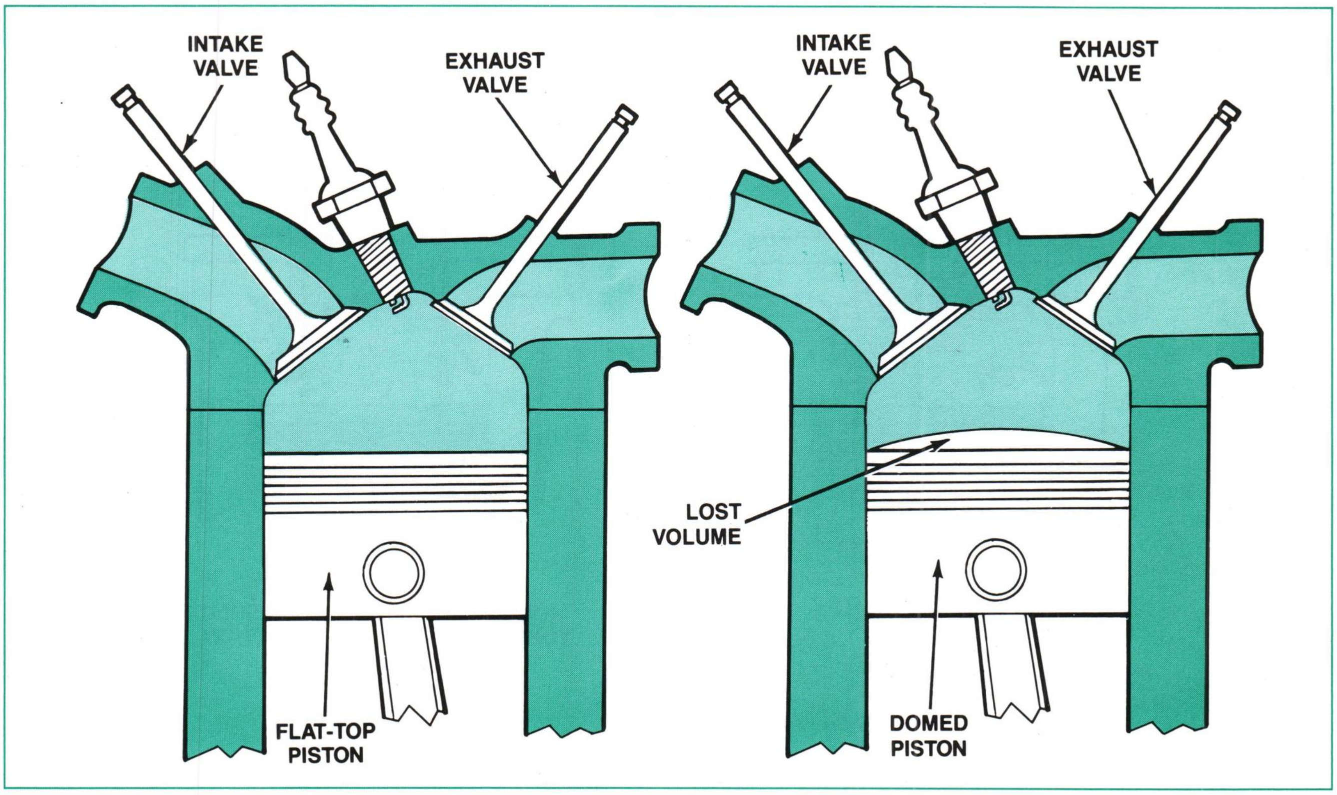

INTAKE VALVE
EXHAUST VALVE
FLAT-TOP PISTON
INTAKE VALVE
EXHAUST VALVE
LOST VOLUME
DOMED PISTON

Figure 46 — Reduced Volume with Domed Piston

fuel economy. However, the greater surface area of the dome can make combustion less efficient, increasing hydrocarbon emissions.

Sometimes, the tradeoff between greater surface area and higher compression can result in better overall efficiency. For example, a higher piston dome enlarges the "squish" areas and increases surface quenching while raising compression (Fig. 47). The increased compression makes combustion in the center of the combustion chamber more efficient, while the surface quenching in the squish areas cools the air/fuel mixture to prevent knocking.

A wedge-shaped dome may be used with a wedge-shaped combustion chamber (Fig. 48). The shape of the piston helps to create turbulence in the combustion chamber, as was discussed earlier in this reference book in the "Cylinder Head/Combustion Chamber" section.

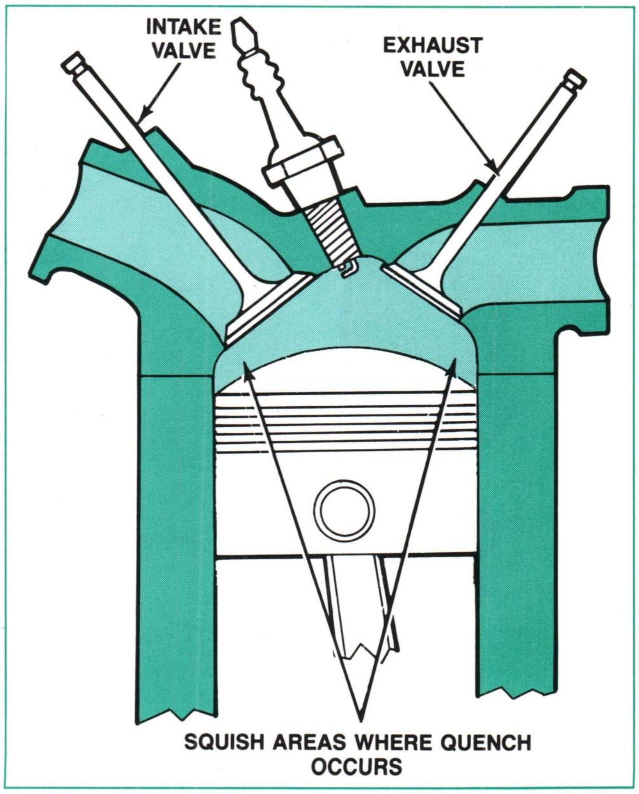

INTAKE VALVE
EXHAUST VALVE
SQUISH AREAS WHERE QUENCH OCCURS

Figure 47 — Higher Piston Dome for Increased Surface Quench

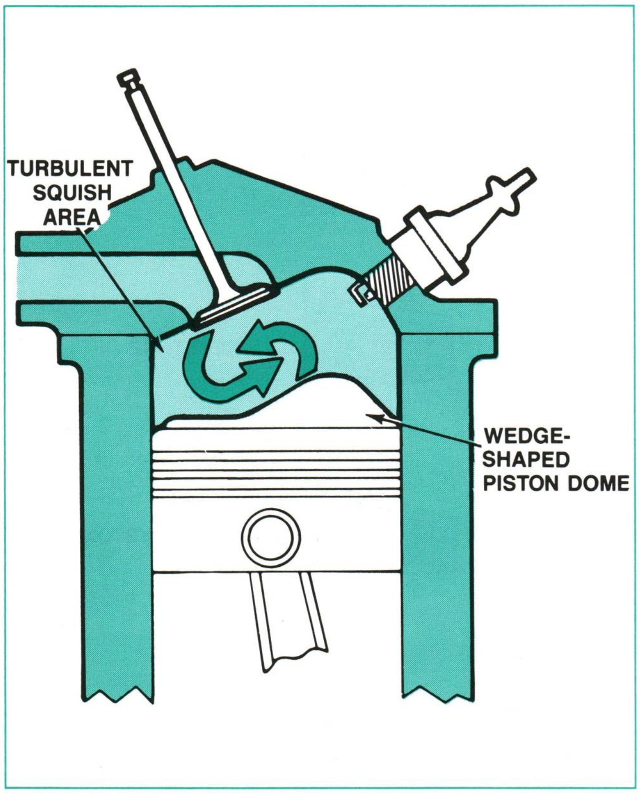


Figure 48 — Wedge-Shaped Piston Dome

For some applications, a combination of the dish and dome designs may be effective. This design (Fig. 49) creates two squish areas in the combustion chamber while maintaining a larger volume than a full dome would allow. As the piston rises, the air/fuel mixture is squeezed from the squish areas into the center of the combustion chamber, causing some turbulence and making combustion more efficient.

Rings

Ring designs vary from one application to the next. Figures 50 and 51 show a selection of ring designs.

In addition, the newer ring materials mentioned earlier have made it possible to design rings with reduced width and tension. Tension is the pressure of the ring against the cylinder wall. A narrower ring has less surface area in contact with the cylinder wall. Less surface area and less pressure mean less friction (Fig. 52).

Another element of ring design that can be adjusted is the location of the rings on the piston. For example, moving the top ring up reduces the crevice volume (Fig. 53). The air/fuel mixture in the crevice does not burn, which increases hydrocarbon (HC) emissions. When the crevice volume is reduced, the amount of unburned air/fuel mixture and of HC emissions is reduced as well.

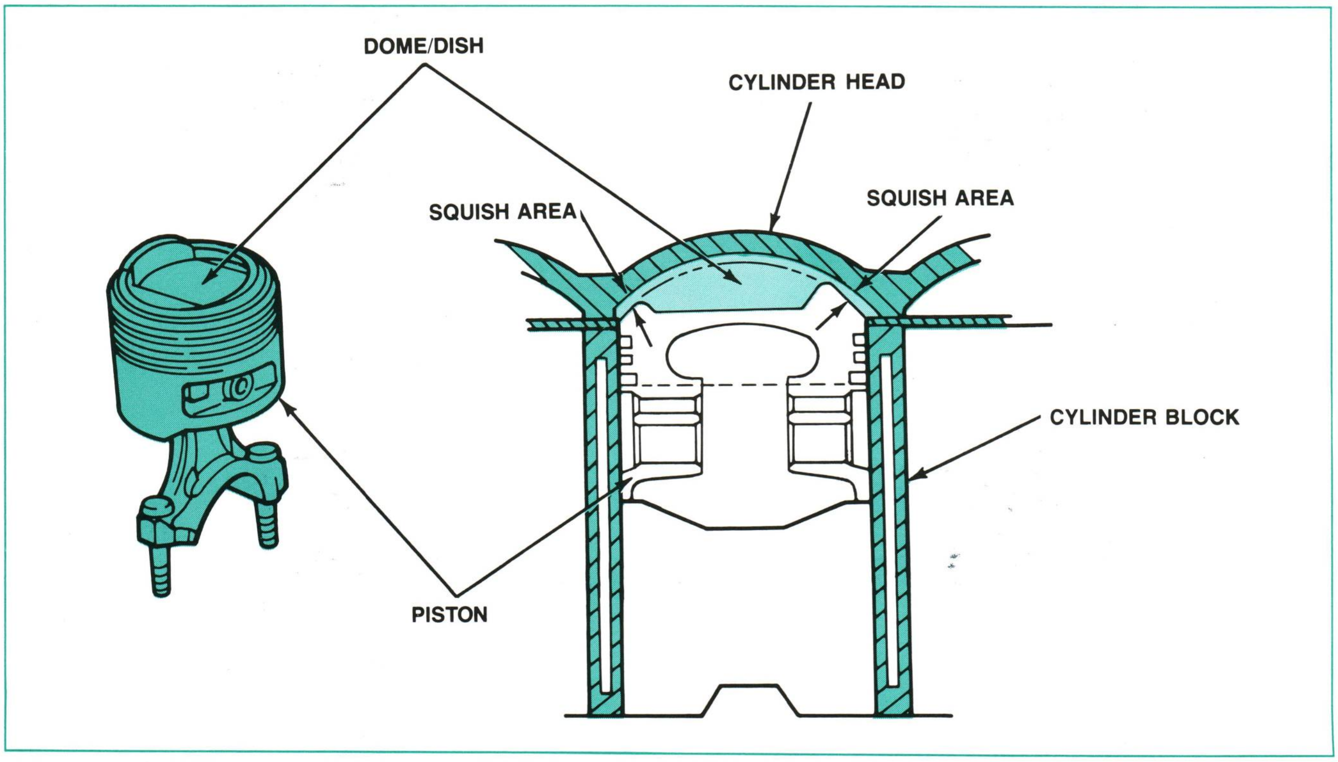


Figure 49 — Dome/Dish Design Piston

PISTONS

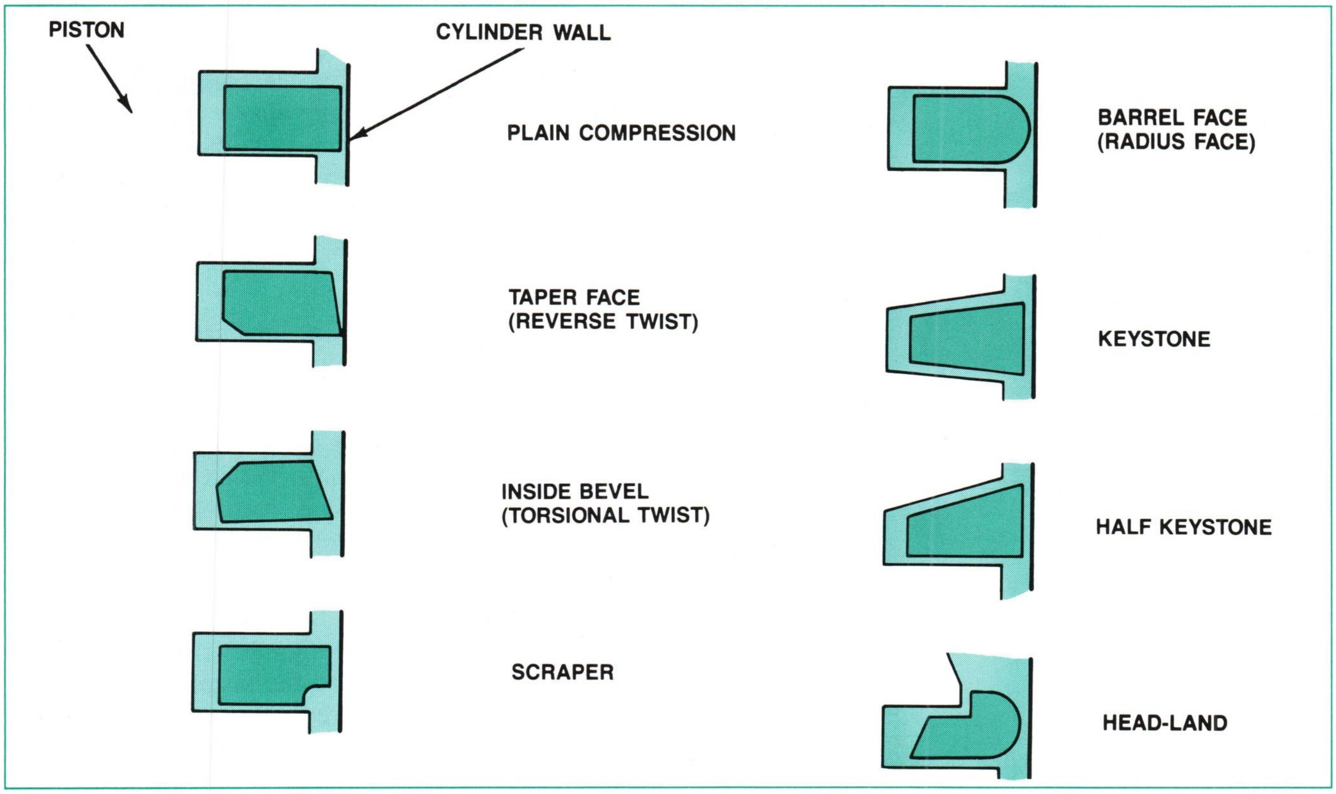

PISTON
CYLINDER WALL
PLAIN COMPRESSION
TAPER FACE
(REVERSE TWIST)
INSIDE BEVEL
(TORSIONAL TWIST)
SCRAPER
BARREL FACE
(RADIUS FACE)
KEYSTONE
HALF KEYSTONE
HEAD-LAND

Figure 50 — Compression Ring Designs

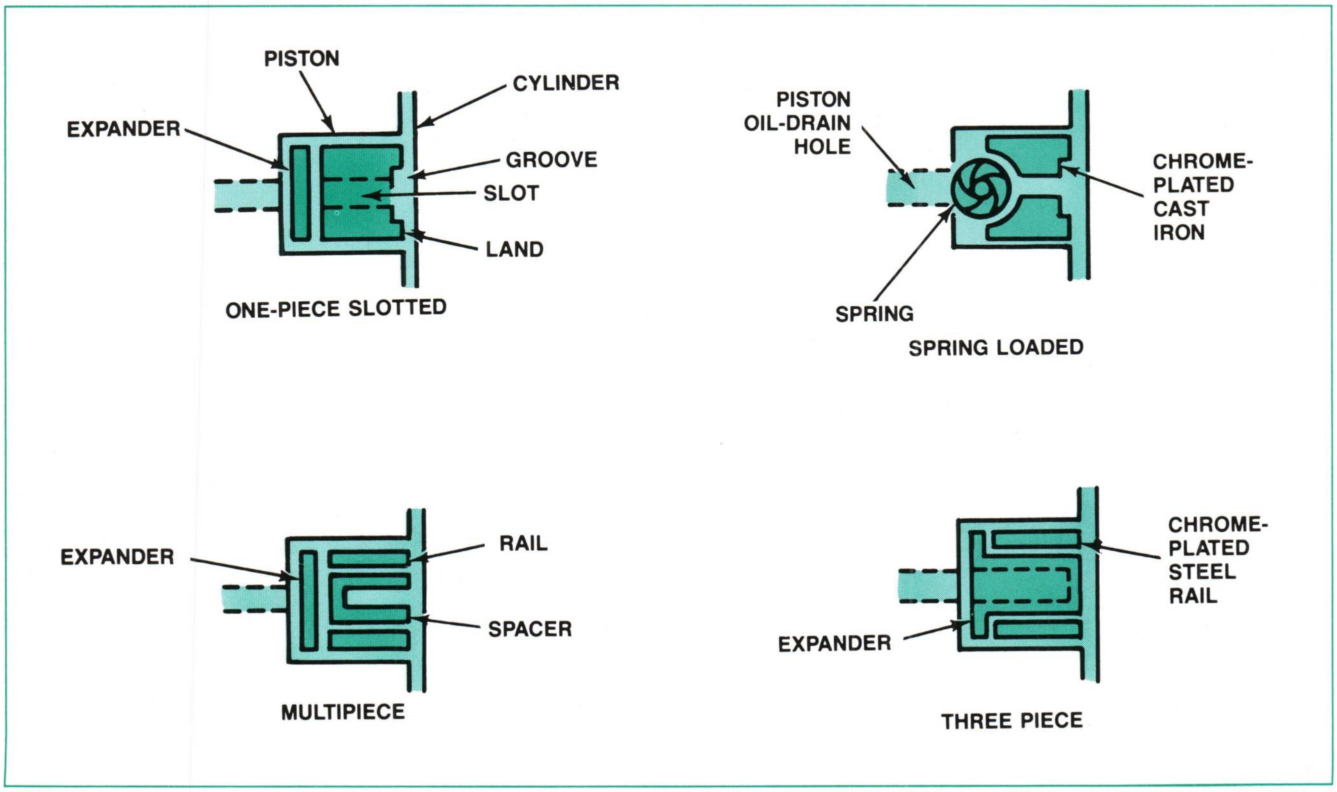

PISTON
EXPANDER
CYLINDER
GROOVE
SLOT
LAND
ONE-PIECE SLOTTED
PISTON
OIL-DRAIN
HOLE
CHROME-
PLATED
CAST
IRON
SPRING
SPRING LOADED
EXPANDER
RAIL
SPACER
MULTIPIECE
CHROME-
PLATED
STEEL
RAIL
EXPANDER
THREE PIECE

Figure 51 — Oil Control Ring Designs

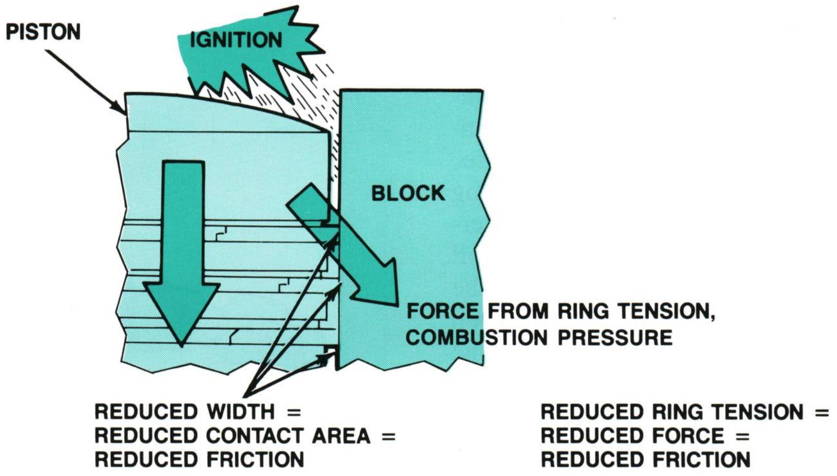

PISTON
IGNITION
BLOCK
FORCE FROM RING TENSION,
COMBUSTION PRESSURE
REDUCED WIDTH =
REDUCED CONTACT AREA =
REDUCED FRICTION
REDUCED RING TENSION =
REDUCED FORCE =
REDUCED FRICTION

Figure 52 — Reduced Width, Low Tension Rings

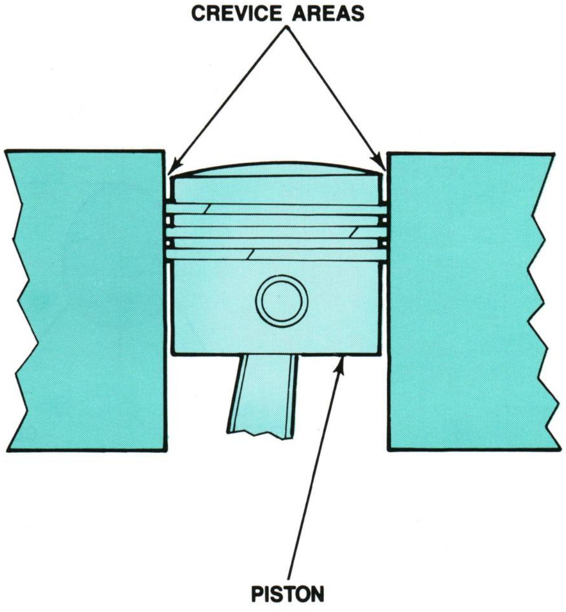

CREVICE AREAS
PISTON

Figure 53 — Higher Top Piston Ring Reduces Crevice Volume

CAMSHAFT

DESCRIPTION

The camshaft (Fig. 54) is a rotating shaft in either the engine block or cylinder head that opens and closes intake and exhaust valves. The shaft is driven by the crankshaft and uses egg-shaped surfaces called cam lobes to open and close the valves. The pointed part of this lobe is the surface that lifts the follower and pushrod, which in turn makes the valve open. The positioning of the lobe on the camshaft is very precise, because it determines the valve opening and closing pattern when the camshaft rotates. The cam lobe determines the lift of the valve, or how far the valve will open (Fig. 55). It also controls the duration of the valve opening, or how long the valve will be open (Fig. 55). The lift and duration vary from one engine to the next, but most automobile engines have moderate lift and short duration for smooth idle and good low end torque.

MATERIALS

The camshaft is made of cast iron, nodular cast iron, or steel and is hardened to resist wear. When roller followers are used in the valve train, the camshaft has to be especially resistant to wear. Billet steel is often used for cams used with roller followers. A billet steel camshaft is actually carved out of a single steel block or "billet" (Fig. 56).

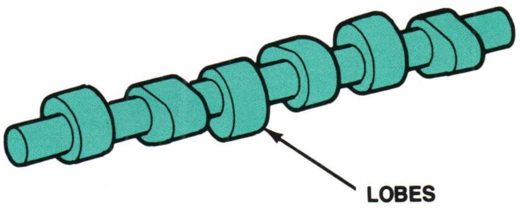


Figure 54 — Camshaft

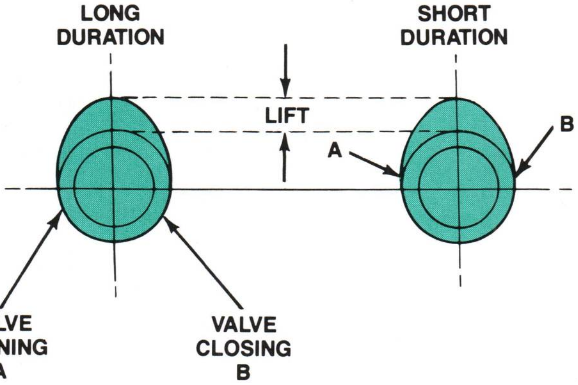


Figure 55 — Cam Lobes

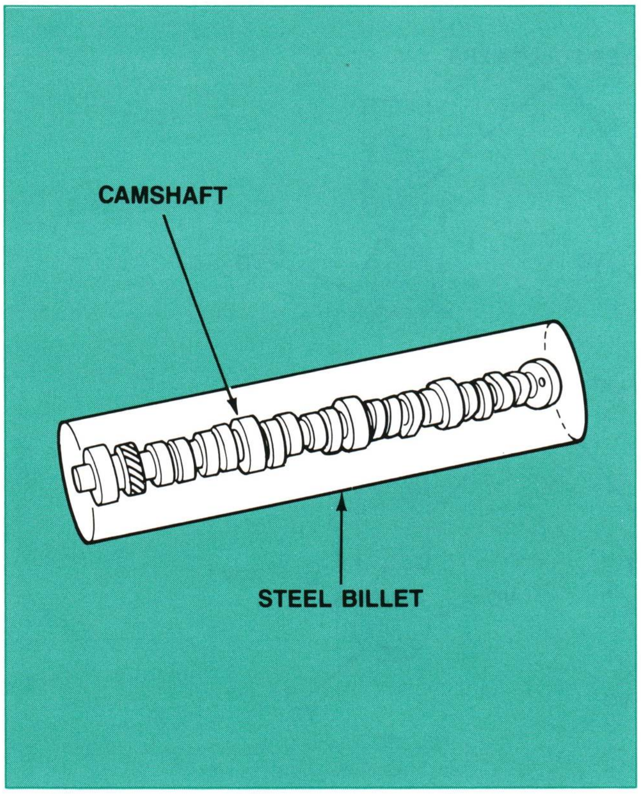


Figure 56 — Billet Steel Camshaft

DESIGN

Lift, Duration, and Overlap

For high performance applications, camshafts that have higher valve lift, longer duration, and more valve overlap are required.

- Higher valve lift simply provides a wider opening so that more air/fuel mixture can enter the combustion chamber.
- Longer duration helps provide extra power and torque at high engine RPMs by overcoming inertia of the intake air. Since the air does not start entering the chamber immediately when the valve opens, some of the valve-open time at the beginning of the duration is actually wasted. By keeping the valve open longer, more air/fuel mixture can be packed into the combustion chamber for higher volumetric efficiency.
- Increased overlap is often just a product of longer duration. If the intake valve is open longer, the time that both valves are open has to increase. In addition, some exhaust gases may be sucked back into the combustion chamber during valve overlap on the intake stroke. These gases cool the chamber and reduce the formation of oxides of nitrogen, much as an EGR system is designed to do.

On the other hand, in engines where fuel economy is most important, a cam designed for shorter duration and less valve overlap is used.

Roller Cam

The roller type lifters that are used by some manufacturers must be matched to a cam with a specific profile or cam lobe design (Fig. 57). This profile ensures that the rate of lift and the rate of return are within the proper limits to keep vibration and wear to a minimum. When properly matched to the lifters, these types of cams provide reduced friction and increased engine efficiency.

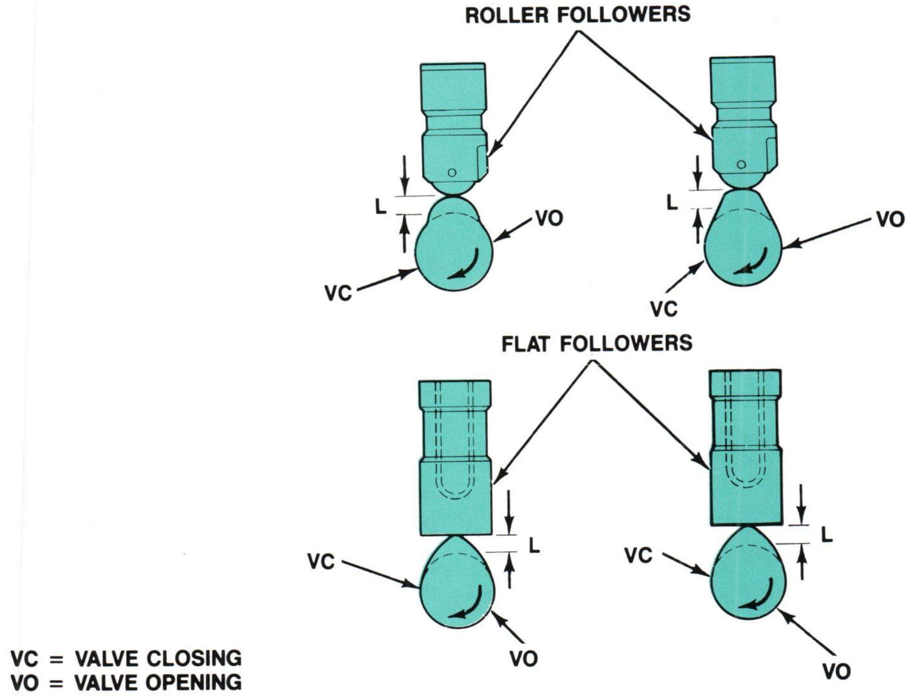
Overhead Cam

The overhead cam is not new — it has been around for many years. However, overhead cam engines have become more popular in recent years. Overhead cams (Fig. 58) are more efficient because they eliminate the need to actuate a pushrod and rocker arm. With fewer pieces in the valve train, valve opening is more precise and more direct. Friction is reduced also. In addition, with an overhead cam, valve placement and geometry can be more flexible, and there are less restrictions on the routing of intake and exhaust passages in the head.

Double Overhead Cam

The double overhead cam design (Fig. 59) divides the job of valve opening between two camshafts, thus helping to reduce wear on each. Double overhead cams are usually used with four- or even six-valve-per-cylinder applications.

CAMSHAFT


ROLLER FOLLOWERS
L
VO
VC
L
VO
VC
FLAT FOLLOWERS
VC
L
VC
L
VO
VO

VC = VALVE CLOSING
VO = VALVE OPENING
L = LIFT

Figure 57 — Cam Profiles

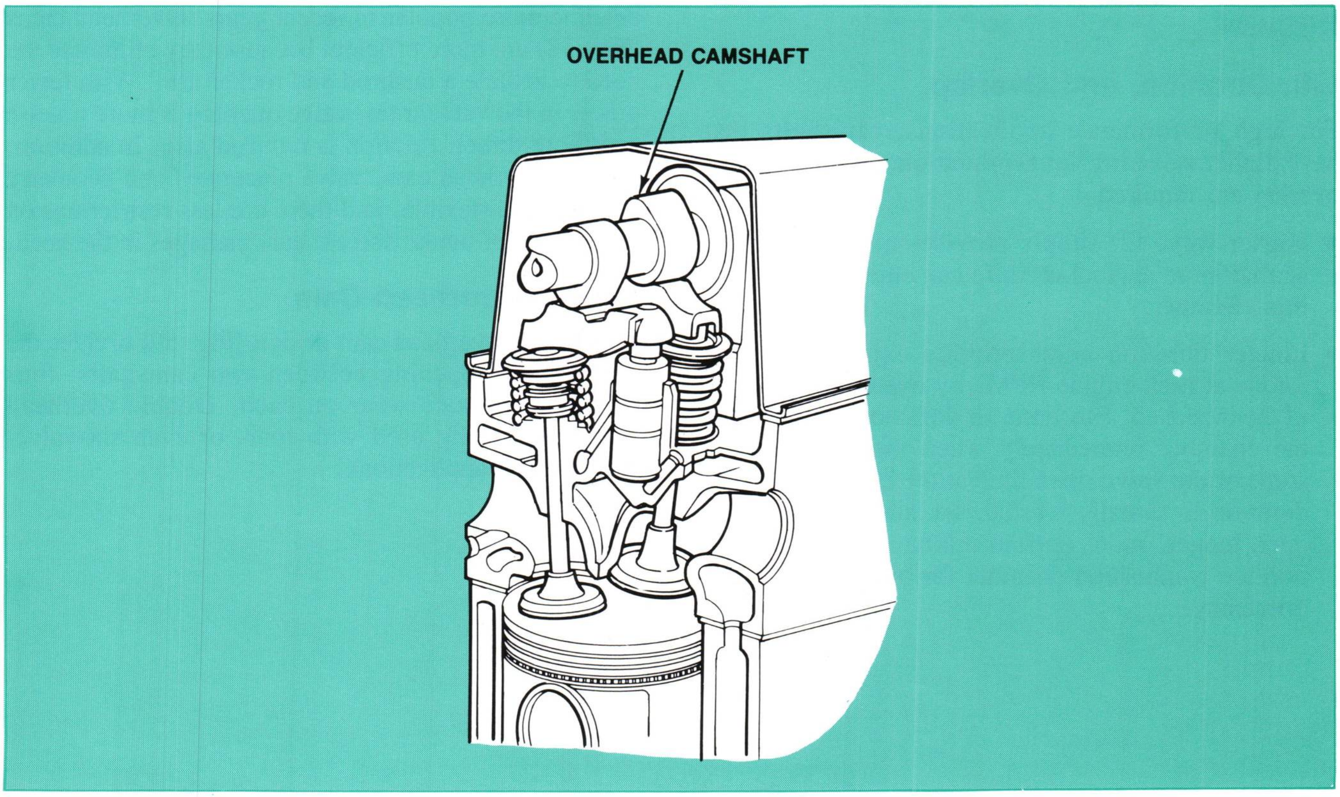

OVERHEAD CAMSHAFT

Figure 58 — Overhead Cam Engine

CAMSHAFT

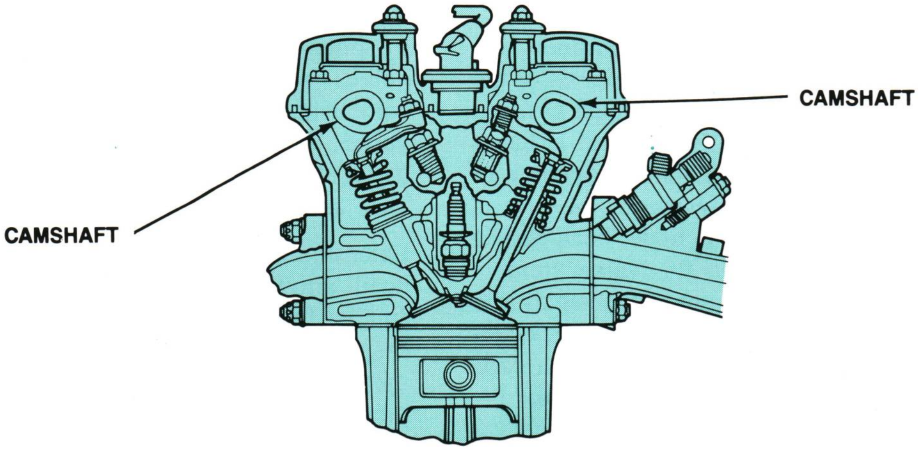

CAMSHAFT
CAMSHAFT

Figure 59 — Double Overhead Cam

VALVE TRAIN

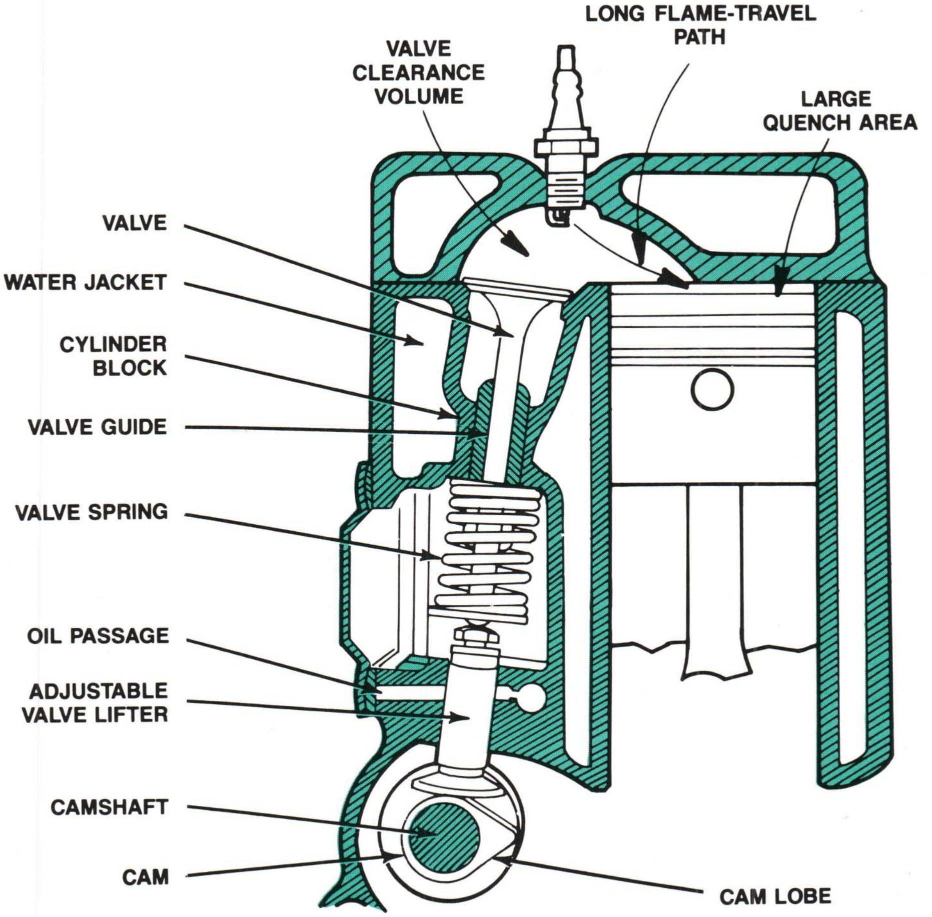
DESCRIPTION

The four-stroke internal combustion engines use intake valves to allow the air/fuel mixture to enter the cylinder, and exhaust valves to allow exhaust gases to purge from the chamber. Both intake and exhaust valves are long stemmed rods that flare at one end to form a beveled disc. During combustion, the disc is the part of the valve that seals the cylinder head part of the combustion chamber. When the valve stem is pressed by the valve train components or camshaft, the valve opens to either let the air/fuel mixture in, or let exhaust gases purge. The valves are opened in a variety of different ways, depending on the engine.

Valving for In-Block Cam Engines

In some early engines that had an in-block cam, the valves were located in the block (Fig. 60). The combustion chamber was offset and centered over the valve rather than over the piston. The long flame travel and large quench area of this design caused slow burn and low thermal efficiency.

Later engine design placed the valves in the cylinder head allowing combustion chambers to be made smaller for better performance. Lifters follow the egg-shaped cam lobe, the push rod uses the lifter movement to move the rocker arm, and the rocker arm presses the valve to open it (Fig. 61).



LONG FLAME-TRAVEL PATH
VALVE CLEARANCE VOLUME
LARGE QUENCH AREA
VALVE
WATER JACKET
CYLINDER BLOCK
VALVE GUIDE
VALVE SPRING
OIL PASSAGE
ADJUSTABLE VALVE LIFTER
CAMSHAFT
CAM
CAM LOBE

Figure 60 — Early In-Block Valving

VALVE TRAIN

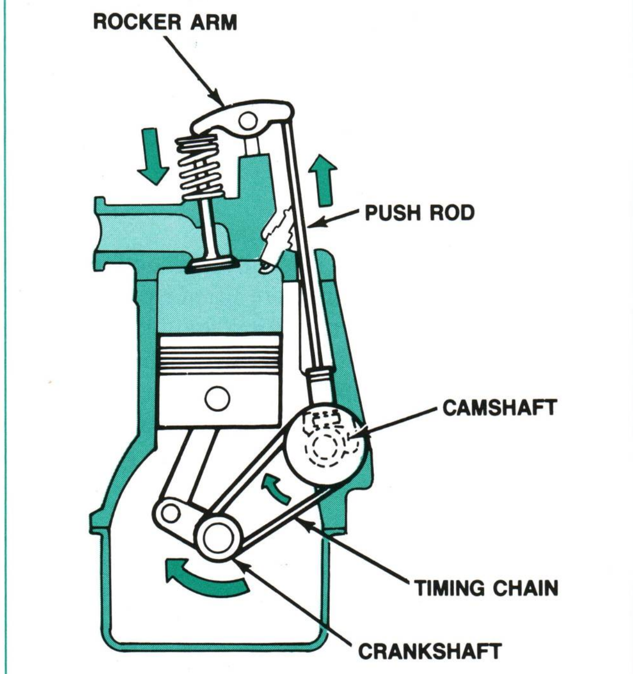

ROCKER ARM
PUSH ROD
CAMSHAFT
TIMING CHAIN
CRANKSHAFT

Figure 61 — In-Block Cam — Overhead Valving

Valving for Overhead Cam Engines

Placing the cam in the head allowed the valves to be opened more directly — by the cam itself, by a cam and follower (Fig. 62), or by a lifter and rocker (Fig. 63).

Valve Train Components

Retaining Hardware

Valves are held in position in the head by several individual pieces (Fig. 64):

- Valve stem keepers — half circle-shaped pieces of tapered metal, used in pairs near the top of the valve to hold the valve in the retainer. Each keeper has an internal boss (or bosses) that mates with the stem grooves at the top of each valve.
- Valve retainer or rotator — allows valve spring pressure to hold each valve in place. When the valve opens, the rotator moves the valve slightly clockwise or counterclockwise.
- Valve spring — returns the valve to the seated position in the head, so that the combustion chamber is well sealed during combustion.

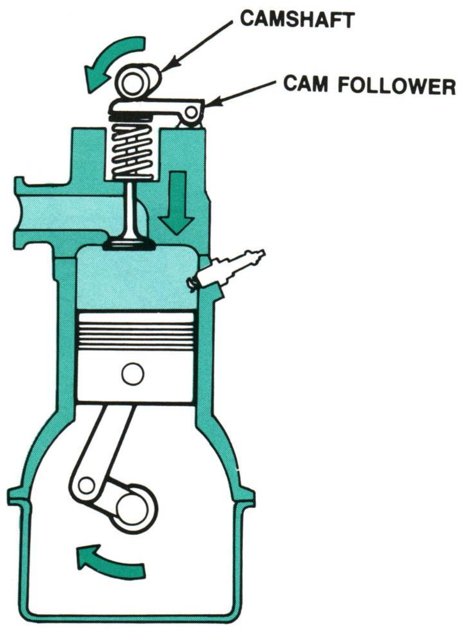

CAMSHAFT
CAM FOLLOWER

Figure 62 — Opening of Overhead Cam Valve — Cam and Follower

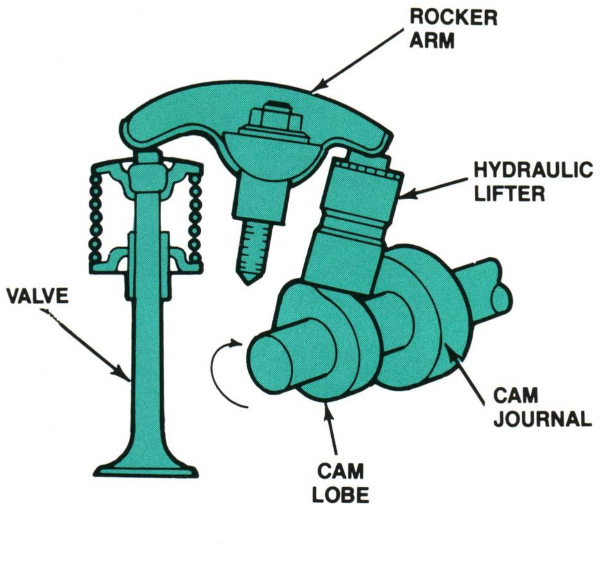

ROCKER ARM
HYDRAULIC LIFTER
VALVE
CAM JOURNAL
CAM LOBE

Figure 63 — Opening of Overhead Cam Valve — Lifter and Rocker

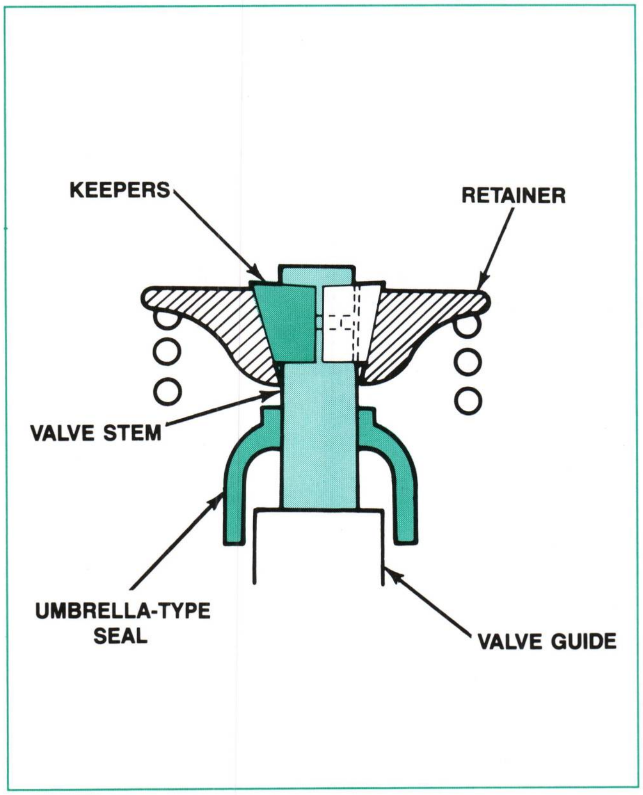

KEEPERS
RETAINER
VALVE STEM
UMBRELLA-TYPE SEAL
VALVE GUIDE

Figure 64 — Valve Train Components

Guides and Seats

The surfaces where the valves contact the head are the guides and seats (Fig. 65). In cast iron heads, the valve seats and guides are often machined right in the cast material. In aluminum heads, the guides and seats are inserts of a much harder material and are pressed into place.

Lifters (Followers)

Valves are opened and closed by the action of the lifters or followers when they are lifted by the lobes of the camshaft. The lifters transform the turning motion of the camshaft into the up and down movement needed to open the valves. As they lift the push rod or rocker arm, the lifters are designed to rotate slightly for even wear. Lifters come in two basic types: solid and hydraulic.

Solid lifters (Fig. 66) are used with some cam profiles to provide good high lift and good performance at high RPMs. They rely on tight clearances and precise movement to open and close the valves. They require occasional adjustment for wear and to keep valve train noise to a minimum.

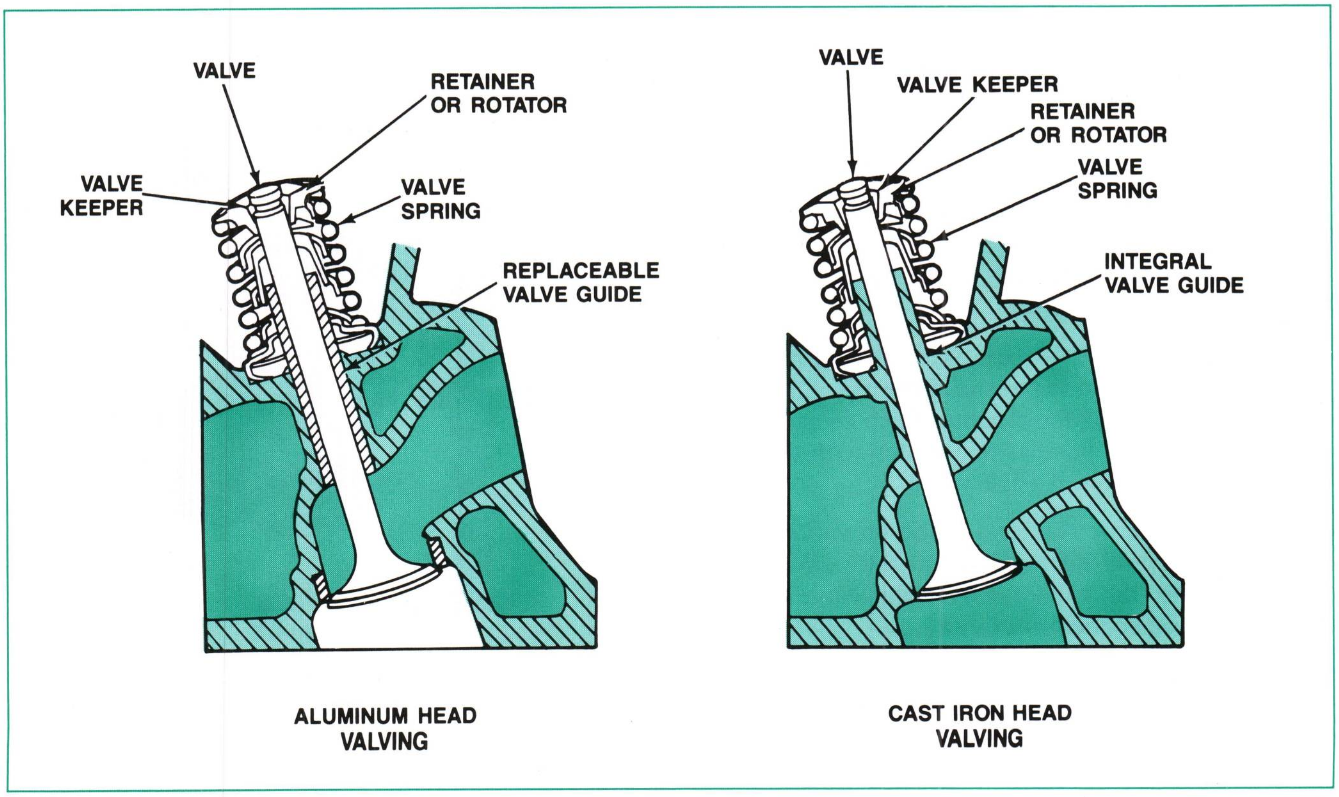

VALVE
RETAINER OR ROTATOR
VALVE KEEPER
VALVE SPRING
REPLACEABLE VALVE GUIDE
ALUMINUM HEAD VALVING
VALVE
VALVE KEEPER
RETAINER OR ROTATOR
VALVE SPRING
INTEGRAL VALVE GUIDE
CAST IRON HEAD VALVING

Figure 65 — Valve Seats and Guides — Aluminum and Cast Iron Heads

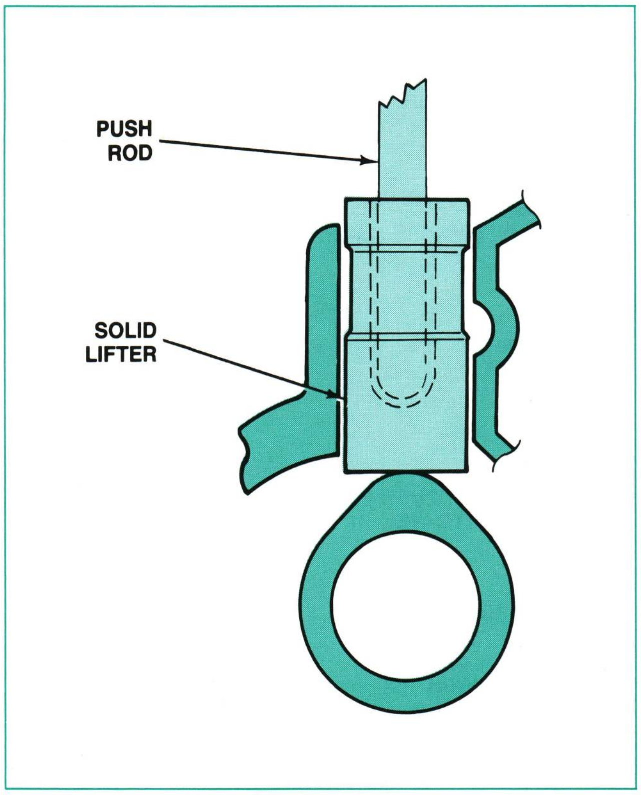


Figure 66 — Solid Lifter

Hydraulic lifters (Fig. 67) help to keep valve train wear to a minimum by using hydraulic action to cushion cam-to-pushrod force. Hydraulic lifters help to provide snug and quiet valve train operation because they use oil under pressure to correct for any minor clearance that may develop.

Push Rods

Push rods are used on overhead valve engines to transfer the force of lifter movement to the rocker arms. Some push rods are hollow and are used to pump oil up to lubricate the rocker arms. In some engines, the push rods can be adjusted to allow for valve train wear.

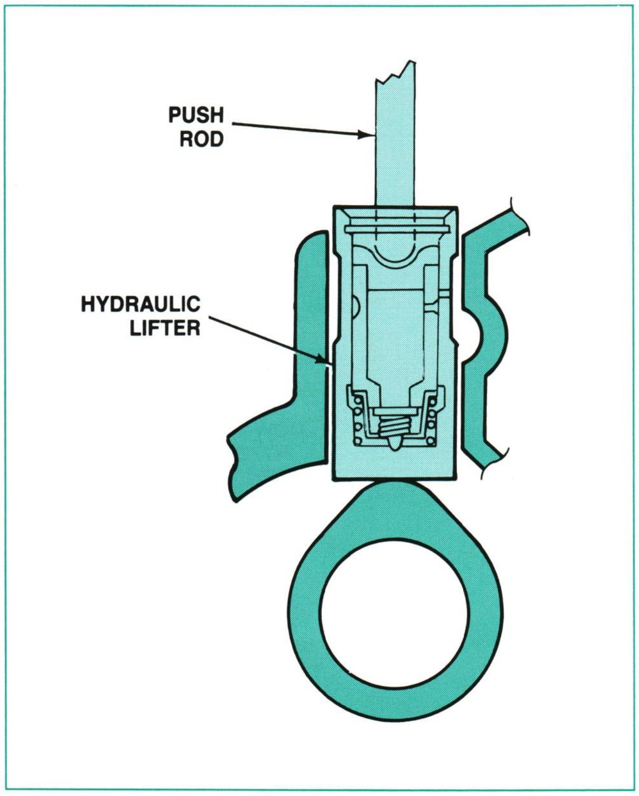


Figure 67 — Hydraulic Lifter

Rocker Arms

Rocker arms (Fig. 68) are used on most overhead valve engines to change upward movement of the lifter and push rod into downward movement needed to open the valves. Usually made from stamped steel, rocker arms often use an "offset" ratio of 1.5 to 1. This means that from the center of the fulcrum or pivot point, one side is one and a half times longer than the other side. This design turns the 1/2 inch of upward lift of the lifter into 3/4 inch downward push that opens the valve. This design keeps the cam lobes small, but it does take more pressure to compress the valve springs and open the valves.

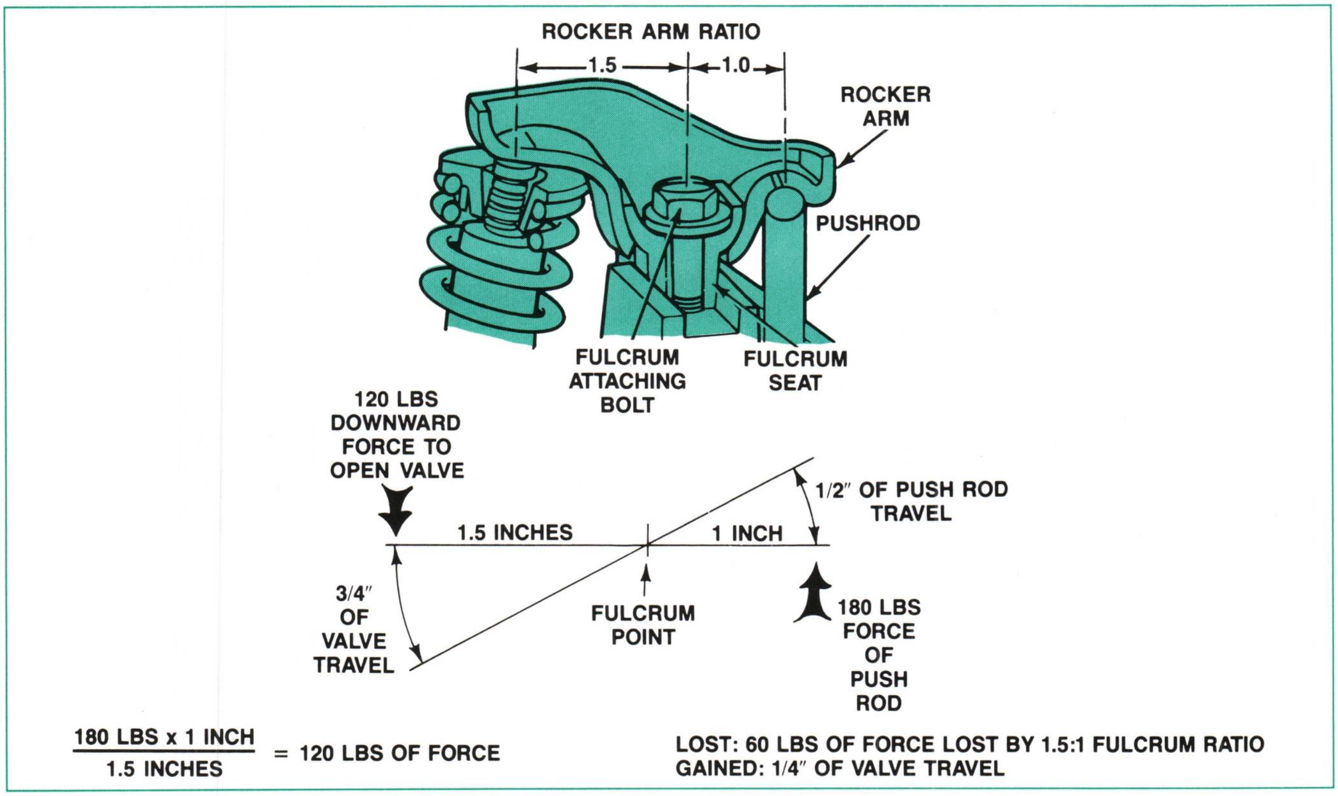

ROCKER ARM RATIO
1.5
1.0
ROCKER ARM
PUSHROD
FULCRUM ATTACHING BOLT
FULCRUM SEAT
120 LBS DOWNWARD FORCE TO OPEN VALVE
1.5 INCHES
1 INCH
1/2″ OF PUSH ROD TRAVEL
3/4″ OF VALVE TRAVEL
FULCRUM POINT
180 LBS FORCE OF PUSH ROD
180 LBS x 1 INCH / 1.5 INCHES = 120 LBS OF FORCE
LOST: 60 LBS OF FORCE LOST BY 1.5:1 FULCRUM RATIO
GAINED: 1/4″ OF VALVE TRAVEL

Figure 68 — Rocker Arm Design and Offset Ratio

DESIGN

Shapes of Valves

The shape of the valve back affects the rate and flow pattern of both the air/fuel mixture as it enters the combustion chamber and the exhaust gas as it leaves. For instance, the flat-backed valve (Fig. 69) allows a great amount of the air/fuel mixture to be drawn into the combustion chamber, but it gives no direction to the flow. For best flow of the mixture into the combustion chamber, the intake port would have to be designed to provide the right swirl and flow up to the valve back. This design works well for some engines.

On the other hand, the normal tulip-shaped valve design (Fig. 69) helps to direct the air/fuel mixture and provide smooth scavenging of the exhaust gases. With higher valve lifts, the opening into and out of the combustion chamber is increased. The additional material on the back of the valve is moved farther out of the way when greater valve lifts are used, which increases volumetric efficiency and performance.

Positive Rotators

Positive rotators (Fig. 70) are used for both the intake and exhaust valves to help minimize wear caused by valve movement. The rotators are mounted on either the tops or bottoms of the valve spring and cause the spring to rotate in one direction as the valve is actuated. The rotation helps reduce seat and guide wear and aids in prolonging valve life and combustion chamber seal. The rotation also helps to remove carbon buildup. Properly operating and seating valves are essential for maintaining good engine performance. The two most common types of valve rotators are shown in Figure 70.

Roller Hydraulic Lifters

One of the most important goals of valve train design is to reduce friction. Roller hydraulic lifters (Fig. 71) reduce lifter-to-cam friction, because the followers roll against the cam instead of rubbing against it as solid and standard hydraulic lifters do. The reduced friction decreases cam wear, improves valve train efficiency and performance, and helps fuel economy. The roller hydraulic lifter can be operated by either an in-block cam or an overhead cam.

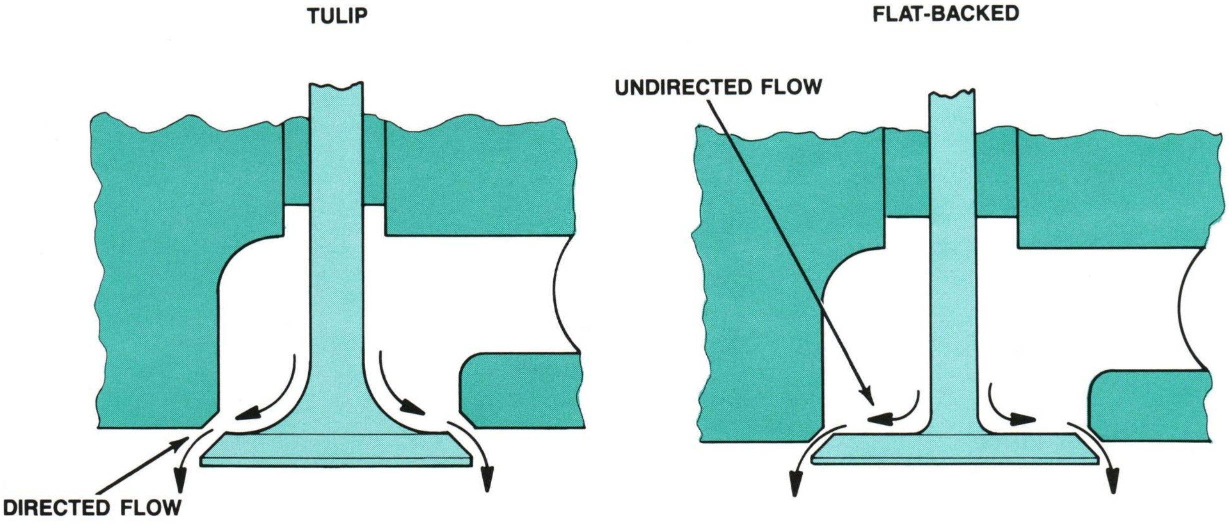

TULIP
FLAT-BACKED
UNDIRECTED FLOW
DIRECTED FLOW

Figure 69 — Valve Designs

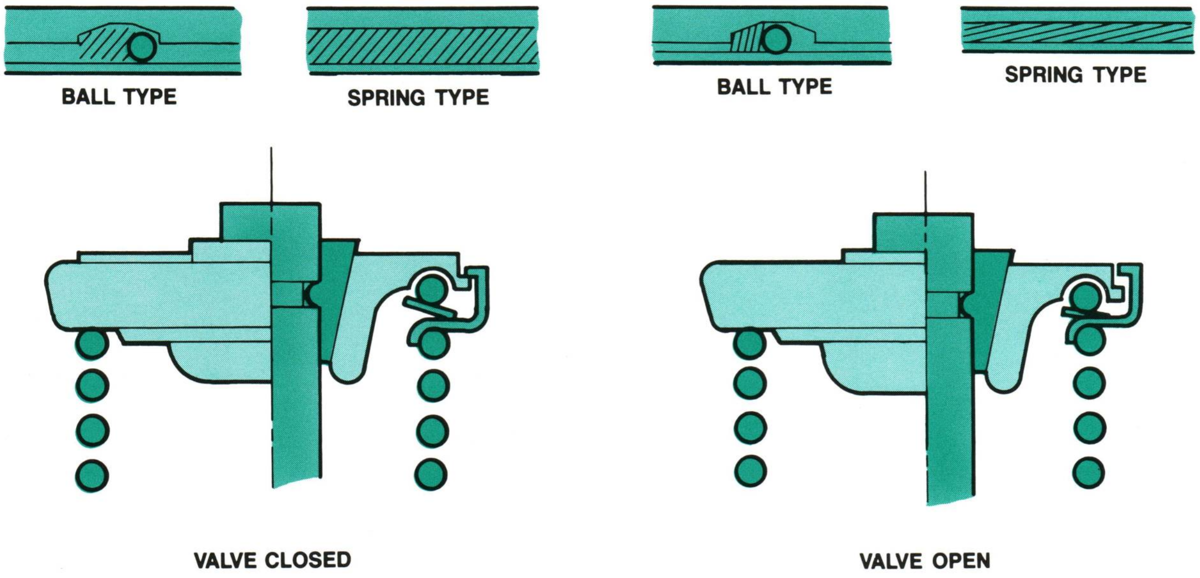

BALL TYPE
SPRING TYPE
BALL TYPE
SPRING TYPE
VALVE CLOSED
VALVE OPEN

Figure 70 — Positive Rotators

VALVE TRAIN

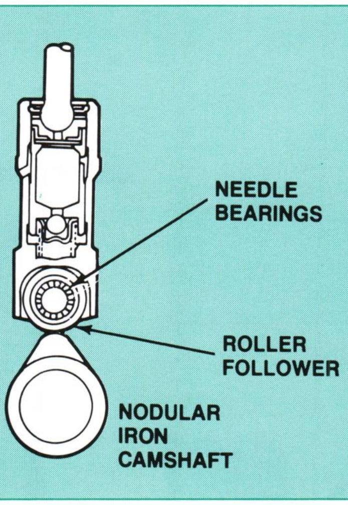


Figure 71 — Roller Lifter

One example of the roller lifter works with the in-block cam (Fig. 72). A guide plate is usually used to keep two roller lifters aligned on the camshaft. This plate keeps the roller lifters from rotating on the camshaft as solid and hydraulic lifters do. The guide plate retainer keeps pressure on the guide plates during operation.

Another roller lifter design is for overhead cam engines (Fig. 73). There is no push rod in this design. The lifter pushes up directly against the rocker arm, which pivots and opens the valve. The rocker arm/valve clearance is adjusted automatically by the hydraulic lifter.

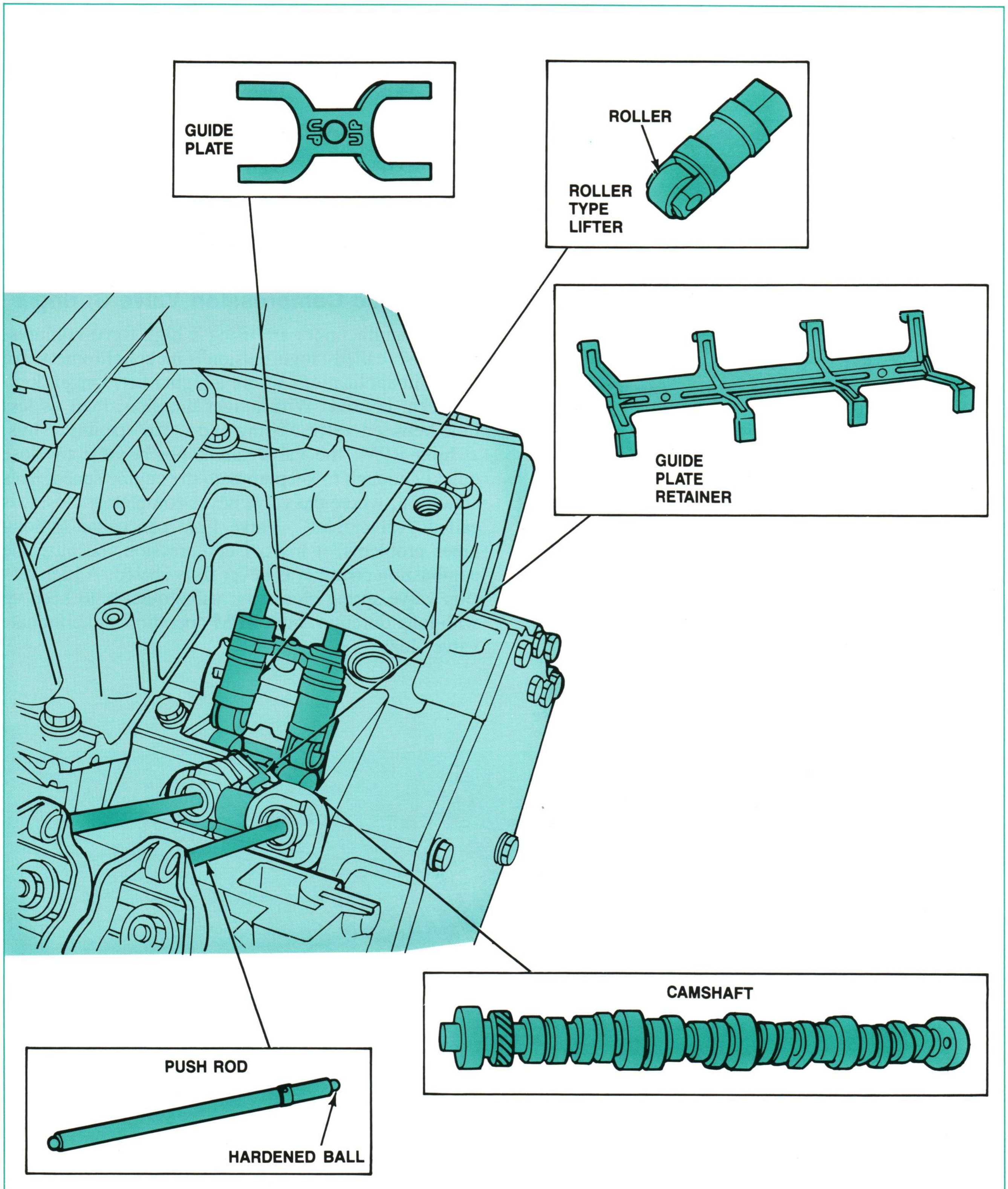

GUIDE PLATE
UP
UP
ROLLER
ROLLER TYPE LIFTER
GUIDE PLATE RETAINER
CAMSHAFT
PUSH ROD
HARDENED BALL

Figure 72 — Roller Lifter — In-Block

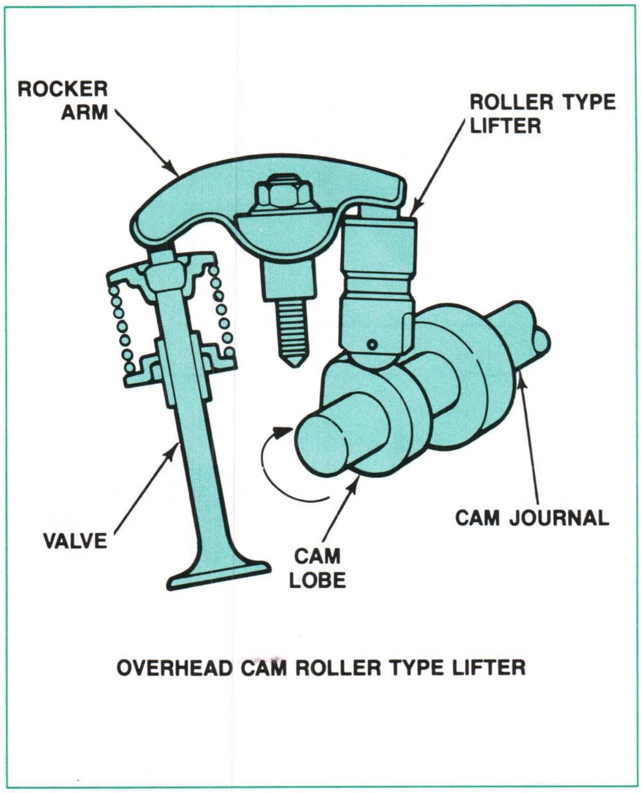

ROCKER ARM
ROLLER TYPE LIFTER
VALVE
CAM LOBE
CAM JOURNAL
OVERHEAD CAM ROLLER TYPE LIFTER

Figure 73 — Roller Lifter — Overhead Cam

Finger Followers

Finger followers (Fig. 74) are used by some manufacturers to keep friction to a minimum and help increase performance. They have less mass than bucket-type valve tappets, but are not as stiff. Finger followers have also been used instead of bucket tappets to reduce engine height and to make valve adjustment easier.

Low Force Compression Valve Spring

For this type of valve spring, the amount of pressure required to open the valves (to force the valve spring to compress) is reduced, without weakening the valve spring's ability to last. This helps to increase gas mileage and camshaft wear on some applications.

High Force Compression Valve Spring

Some manufacturers are using a high force compression (also called "high tension") nickel-chrome valve spring in applications where a higher lift, longer duration cam is used. With longer duration, there is less time between valve closing and valve opening. Thus, at high RPM, the valve might not be able to close quickly enough to keep up with the engine speed. This condition, where the valve never completely closes, is called "valve float." Valve float can cause (among other problems) a loss of compression, because the combustion chamber is never fully sealed. A high tension valve spring closes the valve quickly to keep up with long duration, high RPM operation and eliminate valve float.

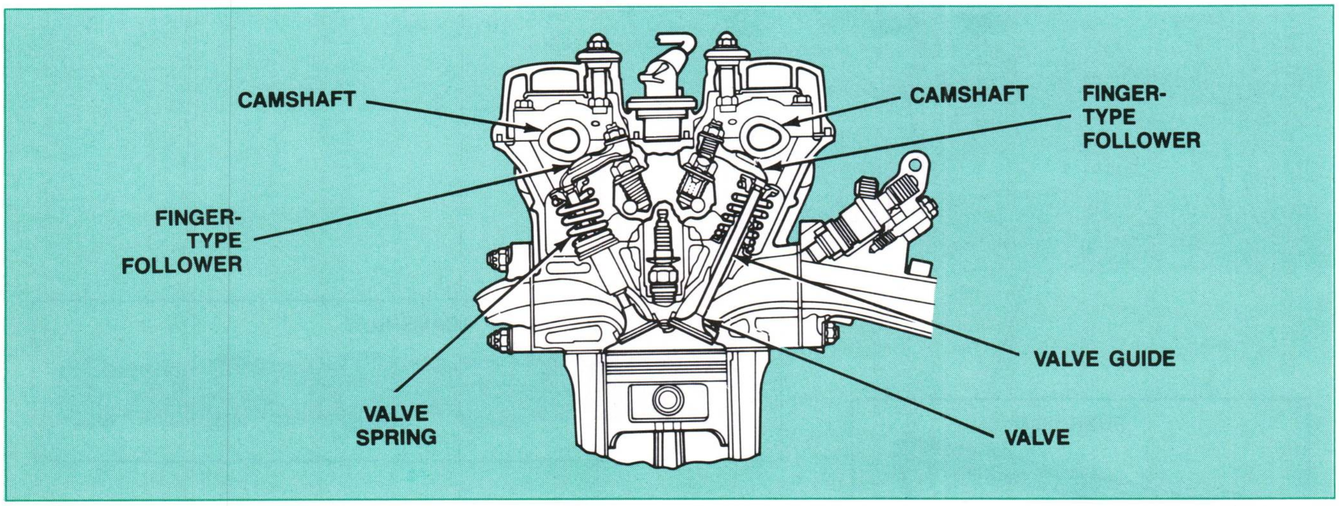

CAMSHAFT
CAMSHAFT
FINGER-TYPE FOLLOWER
FINGER-TYPE FOLLOWER
VALVE GUIDE
VALVE SPRING
VALVE

Figure 74 — Finger Followers

CYLINDER BLOCK

DESCRIPTION

The cylinder block supports the engine components and provides the cooling passages and lubrication passages for these parts (Fig. 75). It contains the cylinders, crankshaft journals, and sometimes the camshaft journals (for in-block cams). These journals are the seating surfaces that the bearings are placed in. The cylinders are either machined in the block material itself or made from special steel or alloy inserts.

The block is usually a one piece casting. This casting is made from material either being poured or pressed into a mold. After molding, the block must be machined so that there are smooth and true mating surfaces for the pistons, cylinder head, oil pan, transmission, valve cover, and other components. The main bearing journals of the crankshaft (and in-block camshaft) are line bored to provide the proper mating surface for the bearings. Line boring means that the block is positioned accurately and securely in a jig and a series of holes are drilled or machined in a straight line.

MATERIALS

Cast Iron

Cast iron is still the material used most often for cylinder blocks. It has the strength and durability needed to withstand heat and friction and support the rest of the engine parts. As we've seen for other parts, cast iron is also very heavy. However, computer-assisted design and manufacturing techniques (CAD/CAM) and advanced casting processes have made today's cast iron engine blocks lighter than earlier ones without any loss of strength.

Aluminum

Aluminum is used by some manufacturers for cylinder blocks because of its light weight. Pressed-in iron cylinder liners (Fig. 76) are usually used with aluminum blocks to provide the necessary durability.

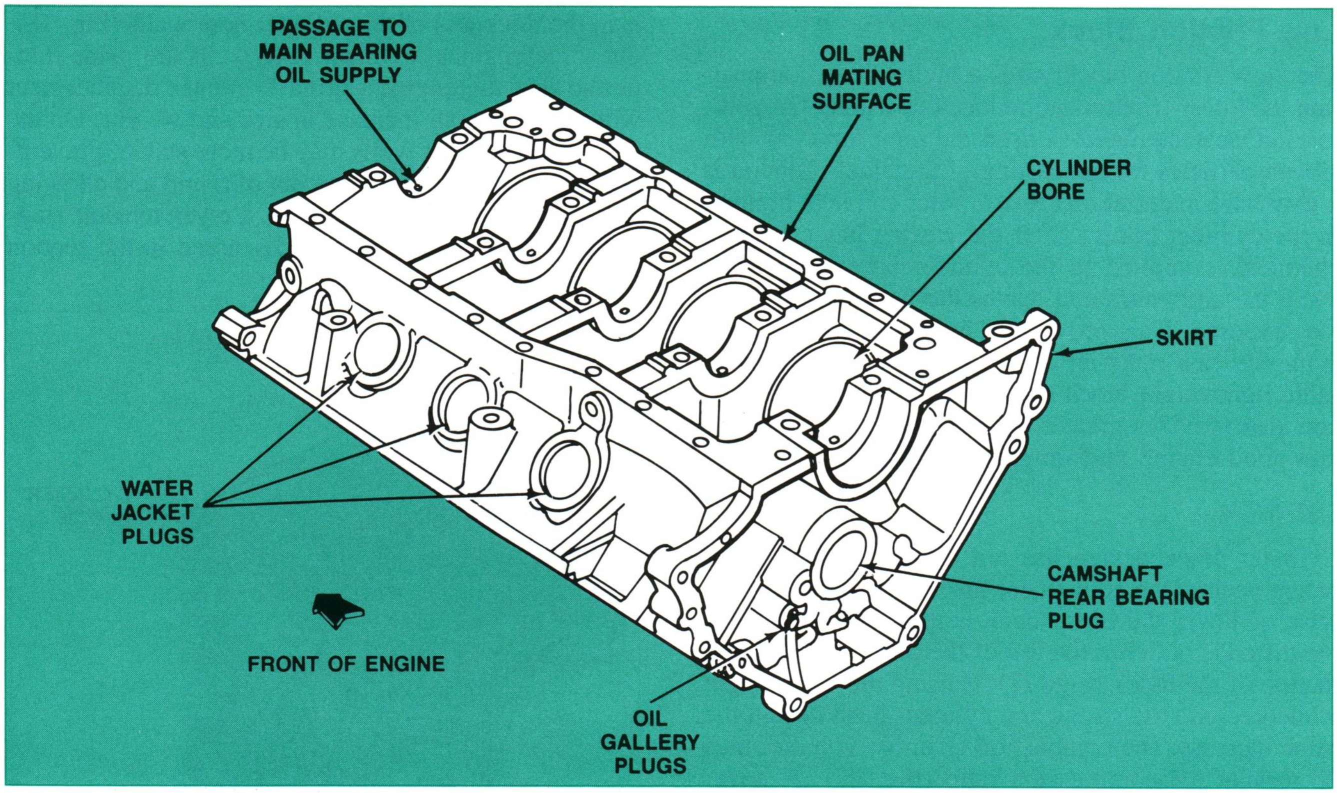


Figure 75 — Cylinder Block

CYLINDER BLOCK

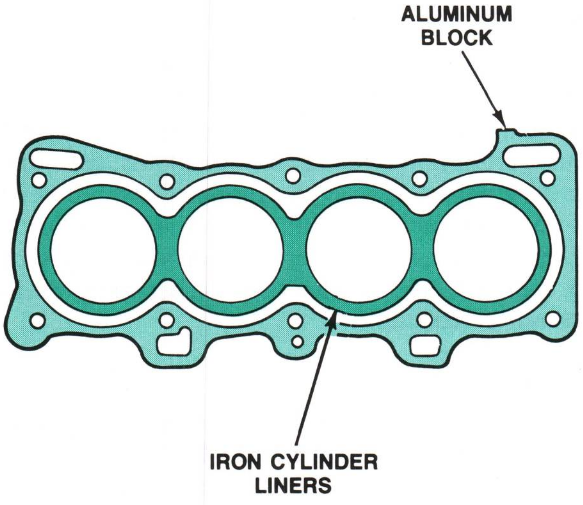


Figure 76 — Aluminum Block with Iron Cylinder Liners

Low Friction Block

The "low friction block" uses a high silicon composition for lower friction and reduced operating temperatures. One manufacturer used aluminum mixed with silicon particles for the casting of the block. Silicon is a very hard material that resists wear and heat buildup in the cylinder bores. After the casting has cooled, a chemical is applied to the cylinder bores that strips away the aluminum and leaves the hard silicon particles exposed. This provides a built-in cylinder lining from the cast material itself, as well as a stronger, more lightweight block overall. The low friction silicon also provides greater ring life and helps to maintain good engine performance, in general.

DESIGN

Cylinder block design has not changed greatly over recent years. One adjustment that has been made is to raise or lower the block deck height. Deck height is the distance between the top of the piston at TDC and the top of the block (Fig. 77). Raising the deck height while keeping the stroke and cylinder head design the same increases the combustion chamber volume, thus decreasing the compression ratio (Fig. 77). A lower compression ratio could be needed to prevent knock if, for example, an engine was switched from carburetion to multi-point fuel injection. The tuned intake manifold that accompanies multi-point fuel injection rams more air/fuel mixture into the cylinder. The added air/fuel mixture could detonate if overcompressed, resulting in engine knock.

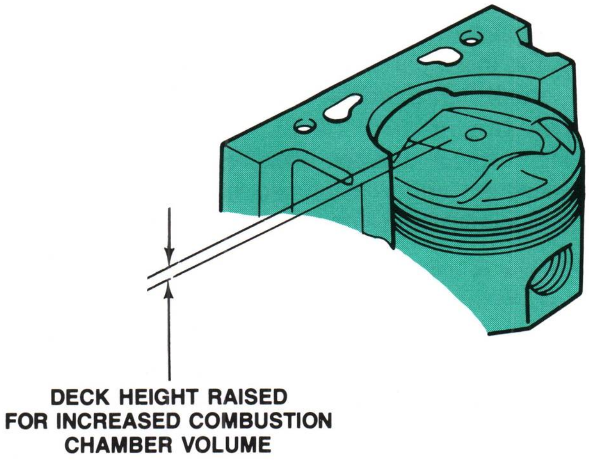


Figure 77 — Engine Block Deck Height

One other place that cylinder block designs may vary is in the thickness of the cylinder bore walls (Fig. 78). On some engines, cylinder bore walls are made thinner so that the engine can have greater displacement without an overall increase in size and weight. On the other hand, thicker walls may be more stable, preventing the cylinders from going out of round and allowing the use of lower tension rings. Lower tension rings produce less friction, as was discussed in the section on "Pistons."

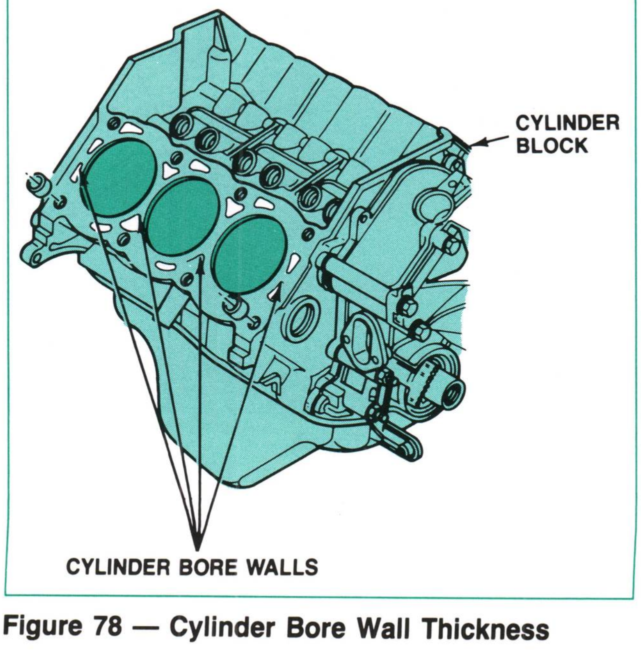


Figure 78 — Cylinder Bore Wall Thickness

CRANKSHAFT

DESCRIPTION

The crankshaft converts the force of piston and rod movement into rotary movement. The crankshaft has contact surfaces for the connecting rods and main bearings called "journals" or "fillets" (Fig. 78). The crankshaft journals must be ground or rolled to the proper diameter to supply the proper main and rod bearing clearances. The crankshaft must also be balanced to withstand high speed rotation. An unbalanced crankshaft would vibrate a great deal as it rotated. This vibration could damage the crankshaft and other engine components. Also, power used up in vibration cannot be used to drive the vehicle. Therefore, counterweights are designed into the crankshaft to maintain balanced rotation. In addition, vibration dampers such as the harmonic balancer and the flywheel (Fig. 80) help the crankshaft to cancel out torsional vibrations and fatigue cracking. The crankshaft also contains oil passages for bearing lubrication (Fig. 79).

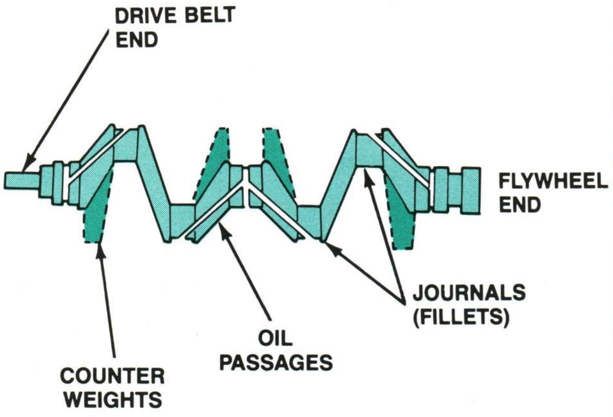


Figure 79 — Crankshaft

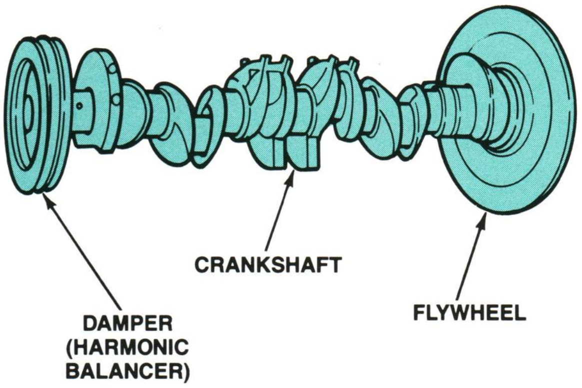


Figure 80 — Crankshaft, Flywheel, and Harmonic Balancer

MATERIALS

Torsional Stiffness

A key consideration in choosing the material used for the crankshaft is "torsional stiffness." Torsional stiffness is the resistance of the material to the torsional or twisting force applied to the crankshaft by the pistons and connecting rods (Fig. 81). Without enough torsional stiffness, the crankshaft could bend, crack, or even break when the engine is running at high RPM or high torque.

Cast Nodular Iron

Cast nodular iron is made with a process that causes the graphite mixed with the iron to form nodules instead of plates (Fig. 82). The nodules make the iron stronger. A cast nodular iron crankshaft is less expensive to make and easier to balance than a forged alloy steel crankshaft. However, forged alloy steel is stronger (more torsional stiffness) than nodular iron. Larger main bearings are sometimes used with cast iron crankshafts to make up for this reduced torsional stiffness. The larger bearings provide added stability.

CRANKSHAFT

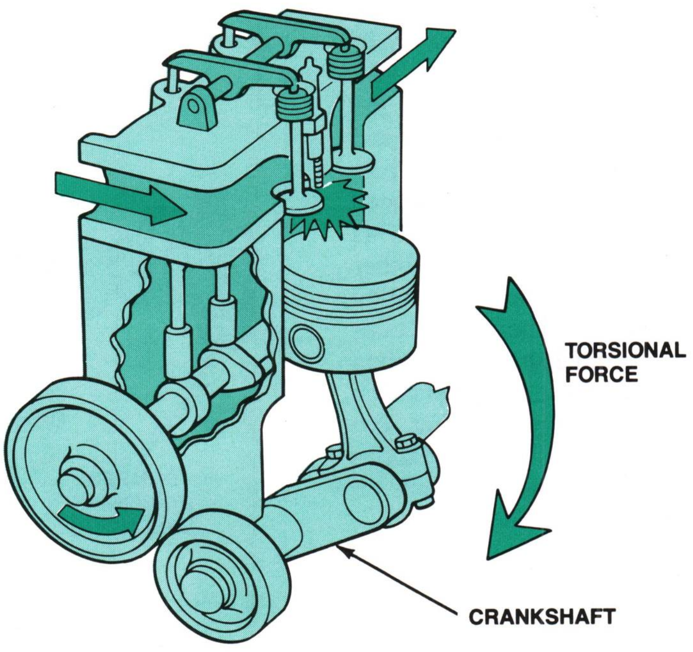

TORSIONAL FORCE
CRANKSHAFT

Figure 81 — Torsional Force Applied

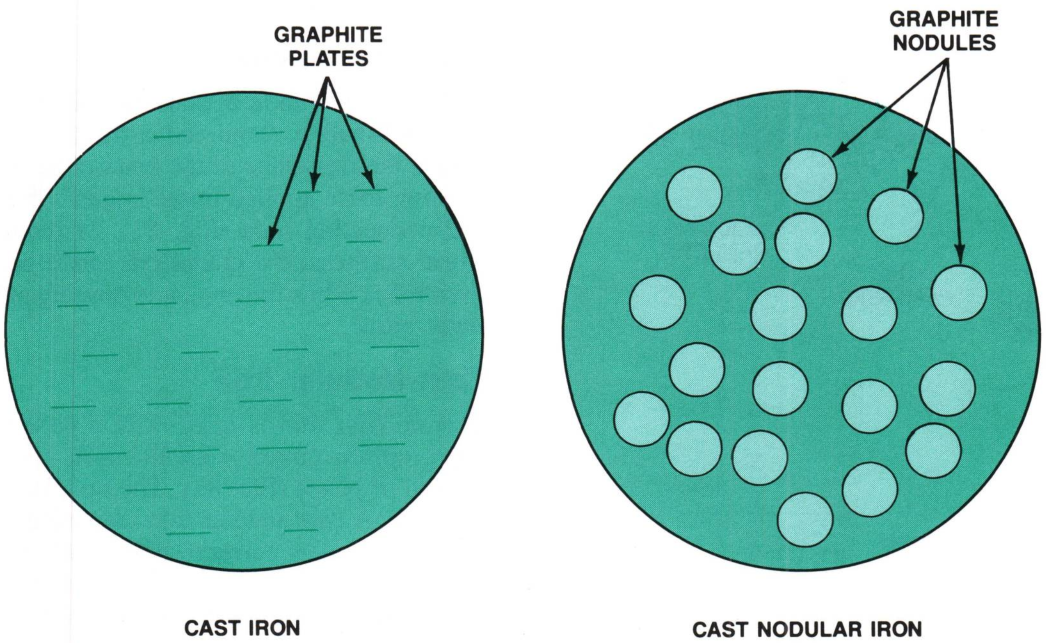

GRAPHITE PLATES
GRAPHITE NODULES
CAST IRON
CAST NODULAR IRON

Figure 82 — Cast Nodular Iron: Cross-Section

CRANKSHAFT

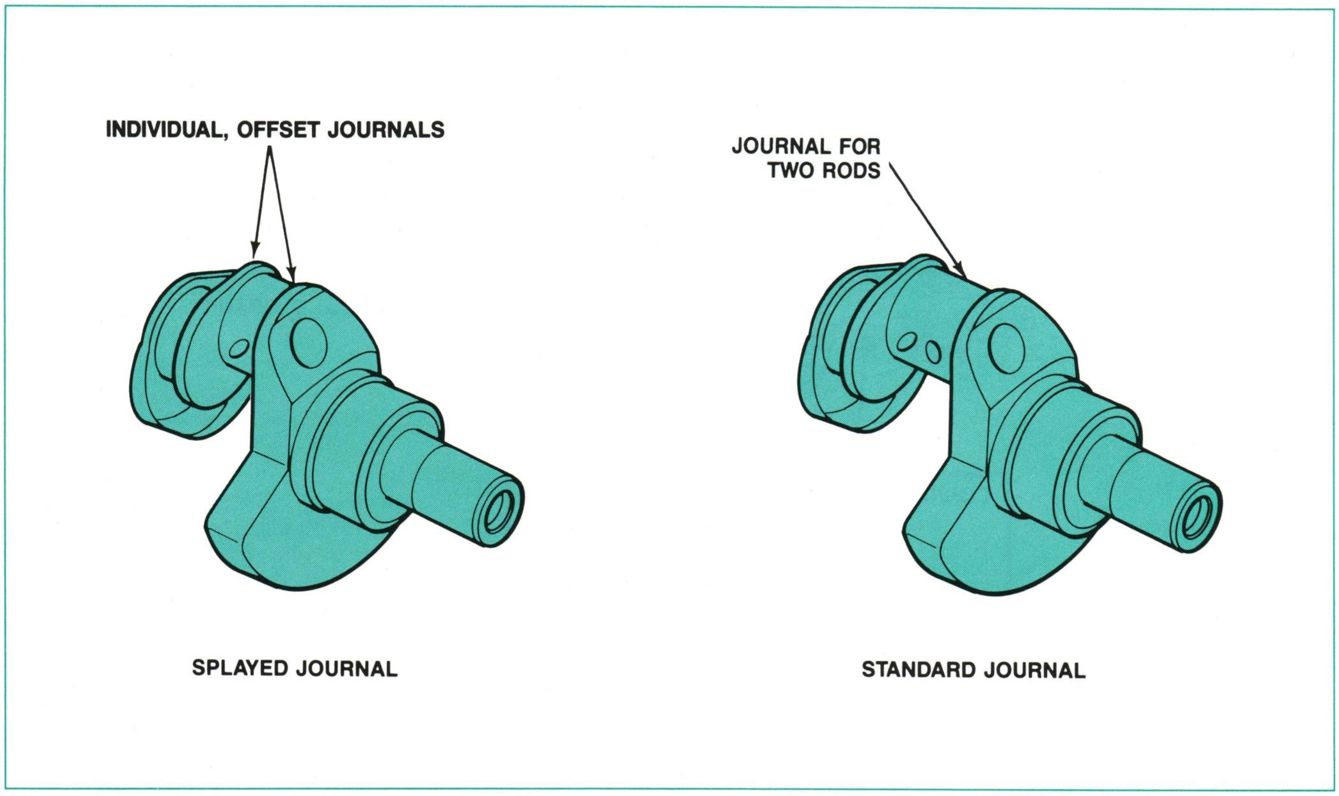


Figure 83 — Improved V-6 Engine Crank Design

Forged Alloy Steel

The other material most used for crankshafts is forged alloy steel. A forged alloy steel crankshaft is stronger (more torsional stiffness) than a nodular cast iron crankshaft. Forged alloy steel crankshafts are used in engines that run at high RPM and/or high torque.

DESIGN

Redesigned V-6 Engine Crankshaft

Several manufacturers have redesigned the 90-degree V-6 engine crank. In the past, the common design was to place two connecting rods on the same crank journal, side by side. This design created an uneven firing sequence and rough idle. The new crankshaft design divides the common journal into two sections and offsets the separated areas by 30 degrees (Fig. 83). This improvement is called "splaying" and has made the idle smoother and aided performance.

Fillet Rolling

The areas of critical stress on a crankshaft are the bearing journal fillets (Fig. 79). Fillet rolling is one way to make the crankshaft stronger and more durable. In this process, the fillets are rolled or squeezed into shape at extremely high pressure. Fillet rolling increases the strength of the fillet area and enables the crankshaft to stand up to the higher RPMs needed for better performance.

Machining the Counterweights

The precise balancing of the crankshaft is very important to engine performance and wear. By machining the crankshaft counterweights for very precise balance, the engine can perform better at higher RPMs, which increases power and economy.

Harmonic Balancers

To help eliminate torsional stress, some manufacturers use the harmonic balancer (small flywheel mounted on the front of the crankshaft) and flywheel in combination. This helps to store rotational energy and to resist sudden fast twisting of the crankshaft. Today's use of the computer for precise balancing of the harmonic balancer/crankshaft/flywheel combination improves fuel economy and reduces torsional vibration.

CONNECTING ROD BEARINGS AND MAIN BEARINGS

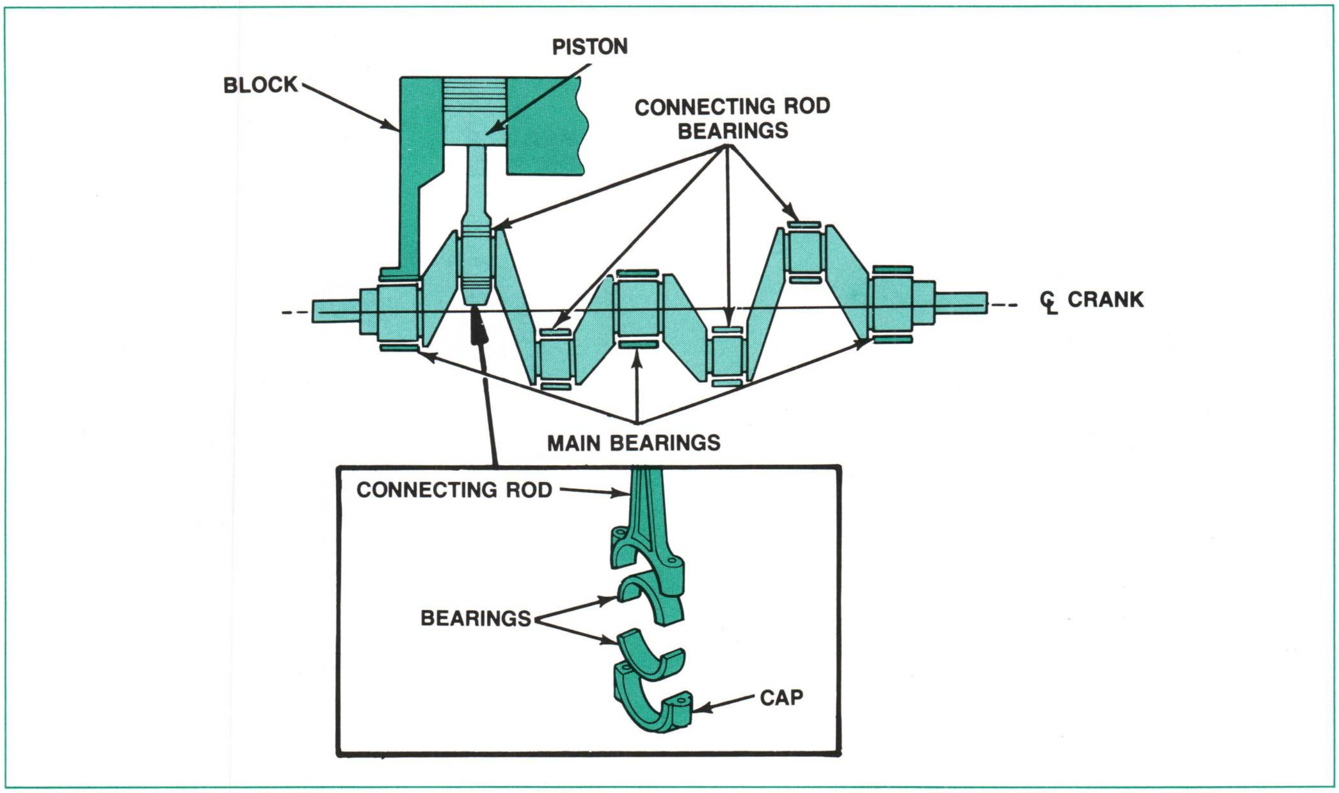


Figure 84 — Bearings

DESCRIPTION

The bearings provide the wear surfaces for the crankshaft. They are located at the points where the connecting rods meet the crank (connecting rod bearings) and the points where the crankshaft meets the block (main bearings) (Fig. 84). They must be soft enough to conform to minor misalignment and able to imbed small particles produced by normal engine wear. They must be able to withstand high temperatures and loads, so the bearings are usually made of two or three layers of different metals or alloys. The inside of the bearing is made of steel or another rigid metal, while the outer layers are made of softer material(s). Some bearings have several layers of platings, coatings, and linings for heavier torque loads, greater RPMs for performance, or hotter operating temperatures. The bearings ride on a film of oil that flows from passages in the crankshaft.

MATERIALS

Rod and main bearings are often lined with tin- or lead-based white metal alloys, copper-lead mixtures, aluminum-tin alloys, or sintered copper (Fig. 85). White metal alloys have been used in the past, but do not have the ability to handle higher RPMs and greater torques of today's engines. A copper-lead lining can handle higher RPMs with less fatigue, but it requires surface-hardened crankshaft journals and greater bearing-to-crank clearance for the best lubrication. Aluminum-tin alloy materials are used most often now for the best thermal conductivity (draws heat away from the crank and disperses it) and wear at higher RPMs.

CONNECTING ROD BEARINGS AND MAIN BEARINGS

DESIGN

The number and placement of main bearings depends on the engine and crankshaft design. Early designs had as few as two bearings — one on each end of the crankshaft, and crankshaft failure was common. All modern crankshafts have a main bearing between every connecting rod journal (Fig. 86). This permits higher revolutions of the crankshaft for improved performance without damaging the crank.

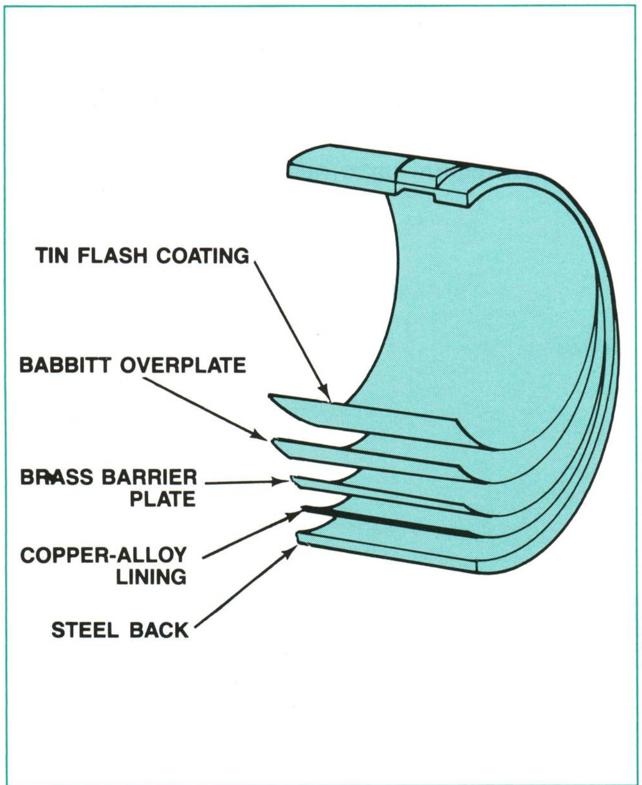

TIN FLASH COATING
BABBITT OVERPLATE
BRASS BARRIER PLATE
COPPER-ALLOY LINING
STEEL BACK

Figure 85 — Bearing Layering (Heavy Duty Example Shown)

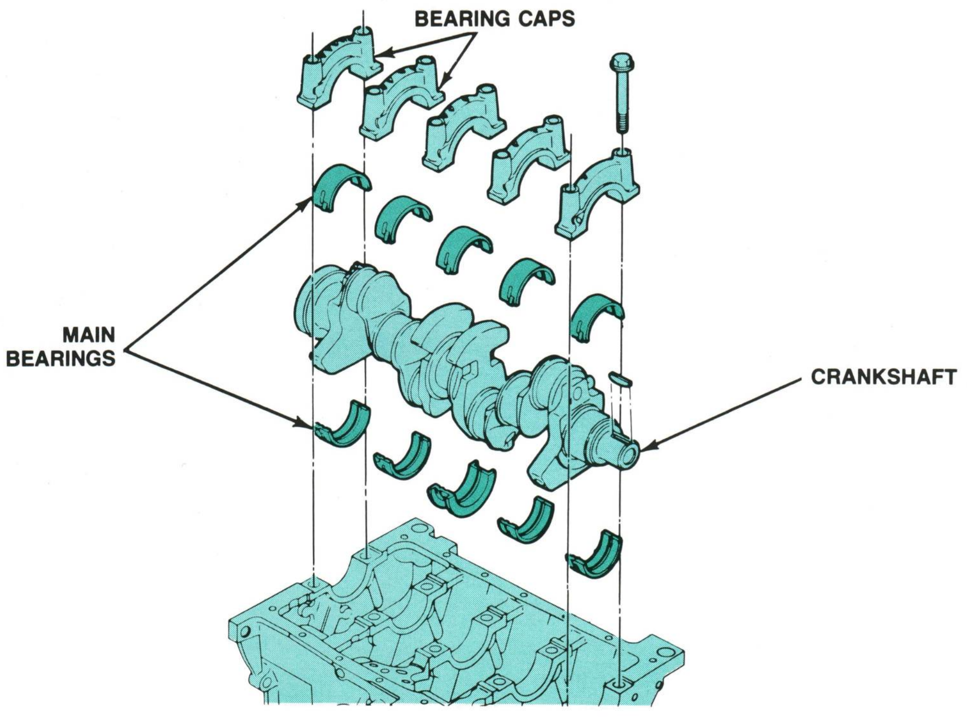

BEARING CAPS
MAIN BEARINGS
CRANKSHAFT

Figure 86 — Main Bearing Placement: Four-Cylinder Engine Shown

INTAKE MANIFOLD

DESCRIPTION

The intake manifold (or manifolds on some engines) directs the intake air and/or the air/fuel mixture to the cylinder head. The carburetor, fuel charging assembly, or fuel injectors are mounted in the intake manifold. As Figures 87, 88, and 89 show, intake manifolds take many different shapes.

MATERIALS

Cast Iron

Cast iron is used for many intake manifolds because it is inexpensive and it is easy to machine. Unfortunately, cast iron is also very heavy. Because of its great weight, cast iron is not used for large, tuned intake manifolds or for applications where engine weight must be kept down.

Cast Aluminum

Unlike cast iron, aluminum is fairly lightweight. It also looks better than cast iron. For these reasons, it is often used on fuel-injected engines and other applications which require large manifolds.

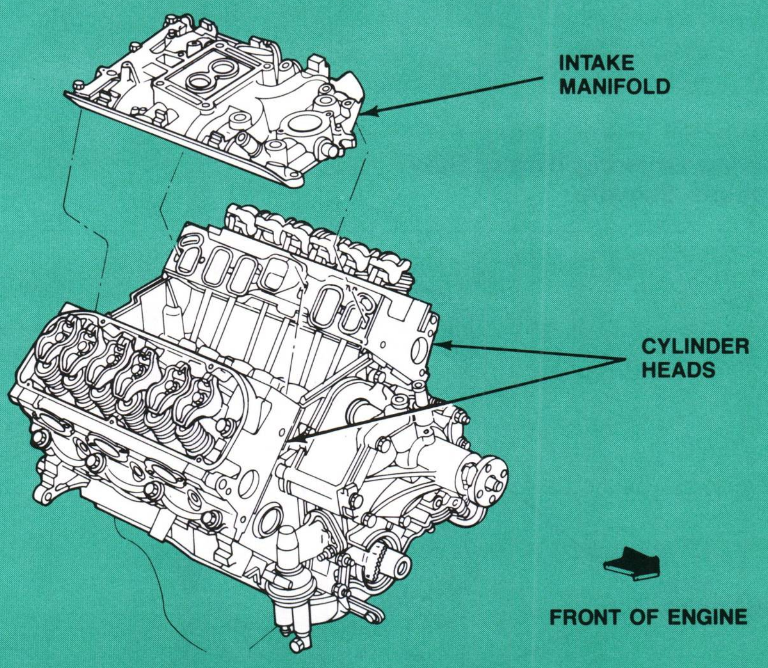


Figure 87 — Intake Manifold: 1982 3.8L V-6 Engine, Carbureted

INTAKE MANIFOLD

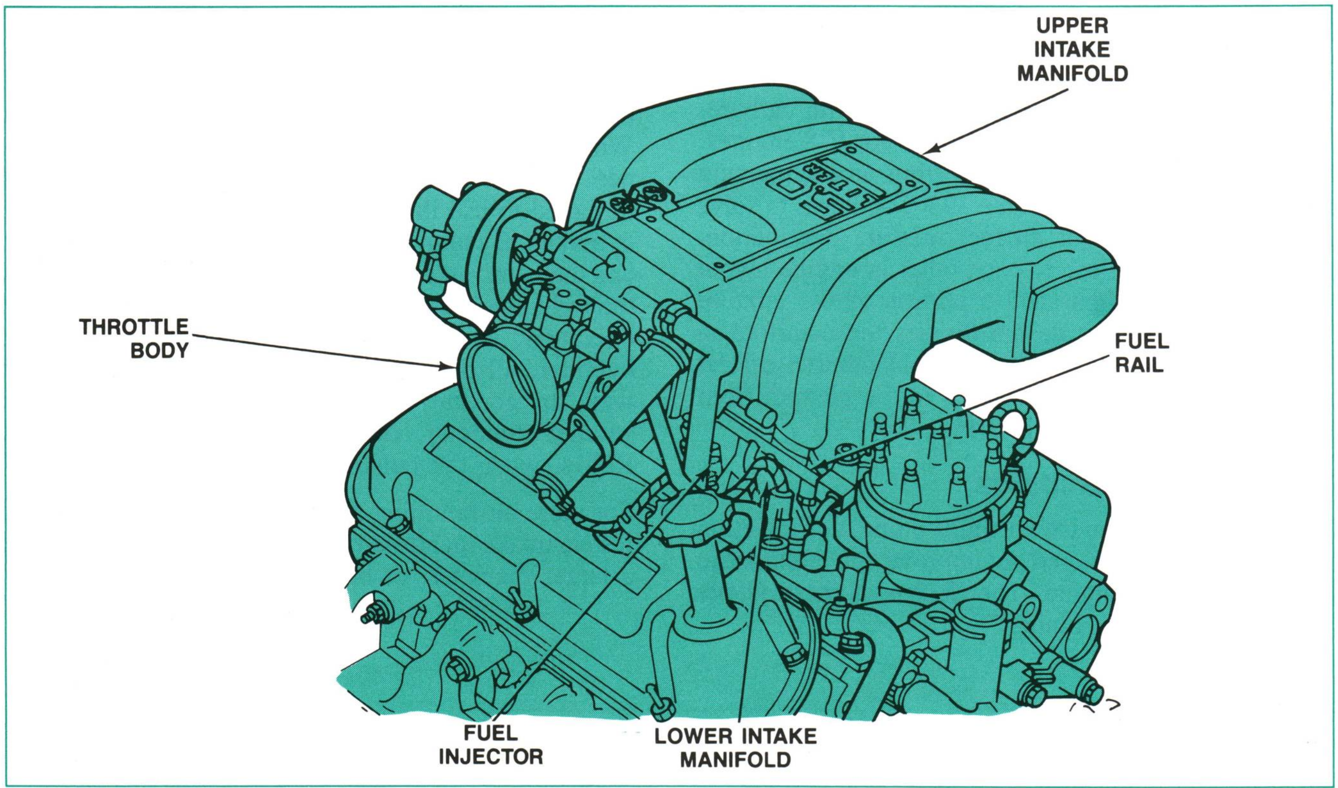

UPPER INTAKE MANIFOLD
THROTTLE BODY
FUEL RAIL
FUEL INJECTOR
LOWER INTAKE MANIFOLD

Figure 88 — Intake Manifolds: 1986 5.0L V-8 Engine Multi-Point Sequential Fuel-Injected

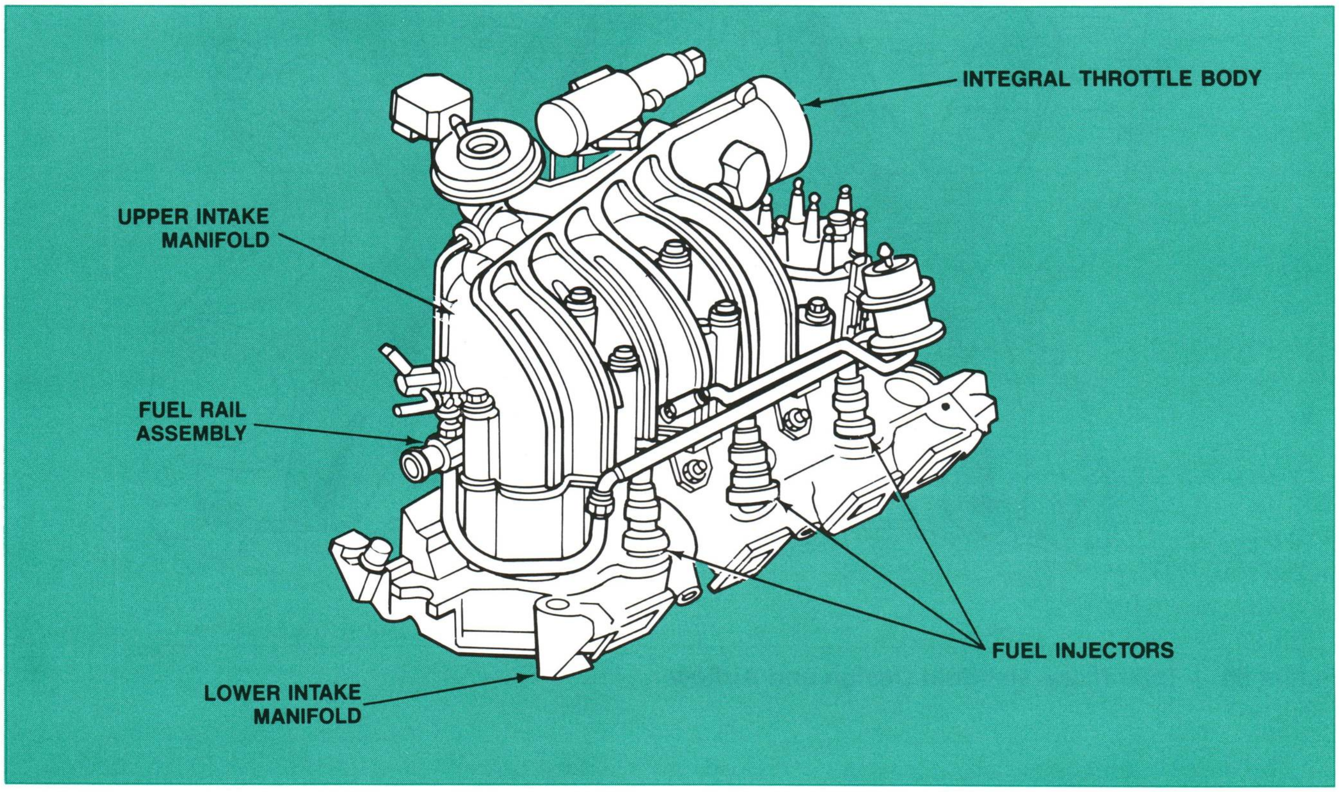

INTEGRAL THROTTLE BODY
UPPER INTAKE MANIFOLD
FUEL RAIL ASSEMBLY
FUEL INJECTORS
LOWER INTAKE MANIFOLD

Figure 89 — Intake Manifolds (with Integral Throttle Body): 1986 3.0L V-6 Multi-Point Fuel-Injected Engine

INTAKE MANIFOLD

DESIGN

The dual plane intake manifold is used with carburetors and central fuel injection systems for V-8 engines. The dual plane design is taken from an engineering thesis that was drawn up in the 1930s and tries to solve a common problem of air/fuel mixture distribution: cylinders that are close to each other in engine layout and firing order often steal a portion of the mixture from each other. The design divides the manifold in half and allows cylinders that would otherwise steal from each other to be connected to the plenum from the other side of the engine (Fig. 90).

Tuned Intake Manifolds

Intake manifolds used with multi-point fuel injection systems can be designed to improve the volumetric efficiency of the engine. The design of these intake manifolds is called "tuning."

The opening and closing of the intake valve causes the air in the manifold to pulse as it rushes into the cylinder (valve open), stops (valve closed), rushes into the cylinder again, and stops again, and so on (Fig. 91). When the manifold is separated into one tube or "runner" for each cylinder (Fig. 91), the runners can be designed to use this pulsing to ram more air into the cylinders. By tuning the runners (adjusting their length and diameter), the manifold can be designed to deliver the right amount of air to the cylinders for best engine operation. To deliver the same amount of air to each cylinder, all the runners must be tuned in the same way. In general, runners that are longer, have a smaller diameter, or both ram more air at lower RPMs, when the pulsing is slower (Fig. 91).

For more air ramming at high RPMs, when pulsing is faster, intake manifold runners should be shorter, have a larger diameter, or both (Fig. 92).

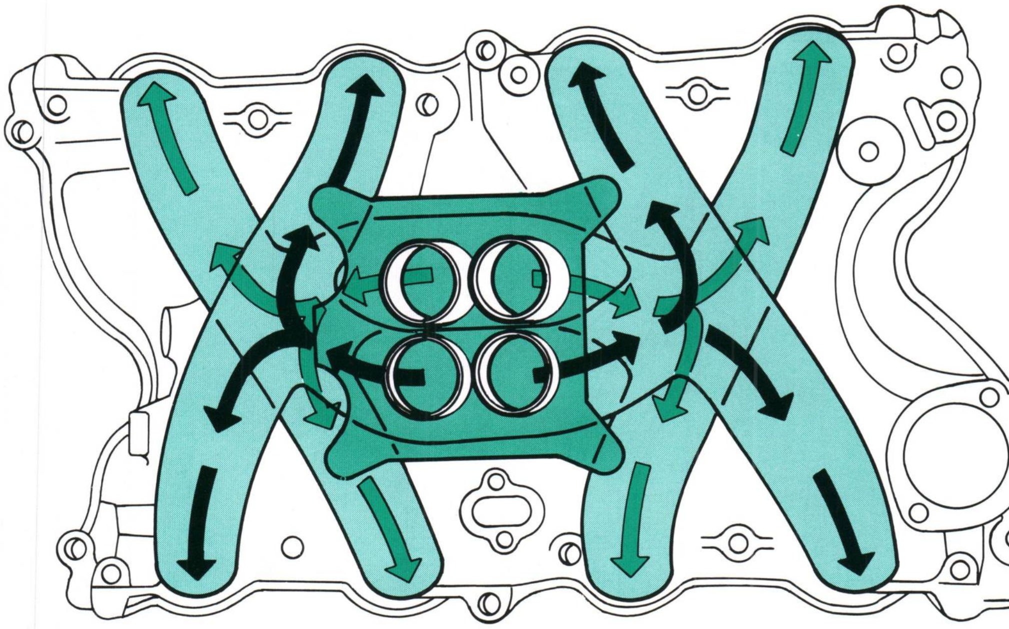


Figure 90 — Dual Plane Manifold Design and Airflow

INTAKE MANIFOLD

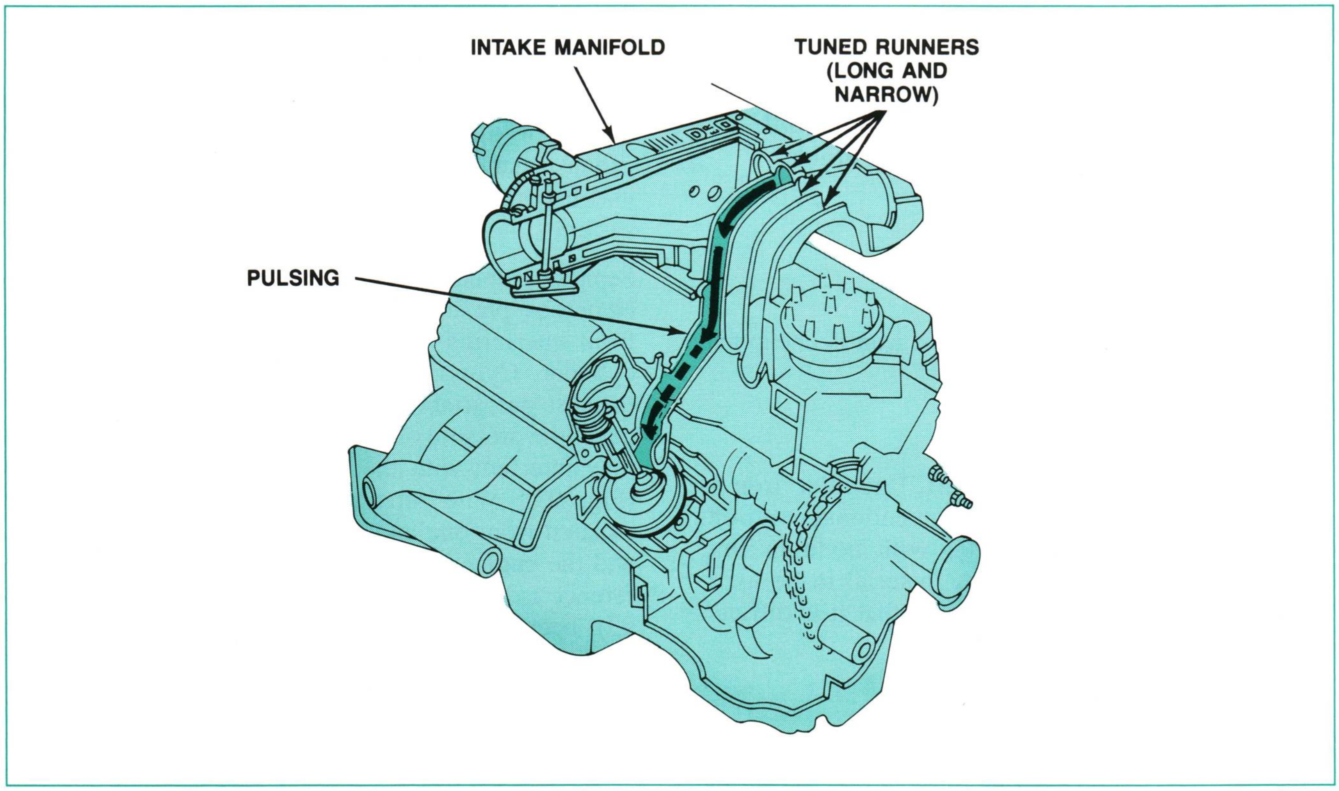

INTAKE MANIFOLD
TUNED RUNNERS (LONG AND NARROW)
PULSING

Figure 91 — Intake Tuning: 1987 5.0L, V-8, Multi-Point Fuel-Injected Engine

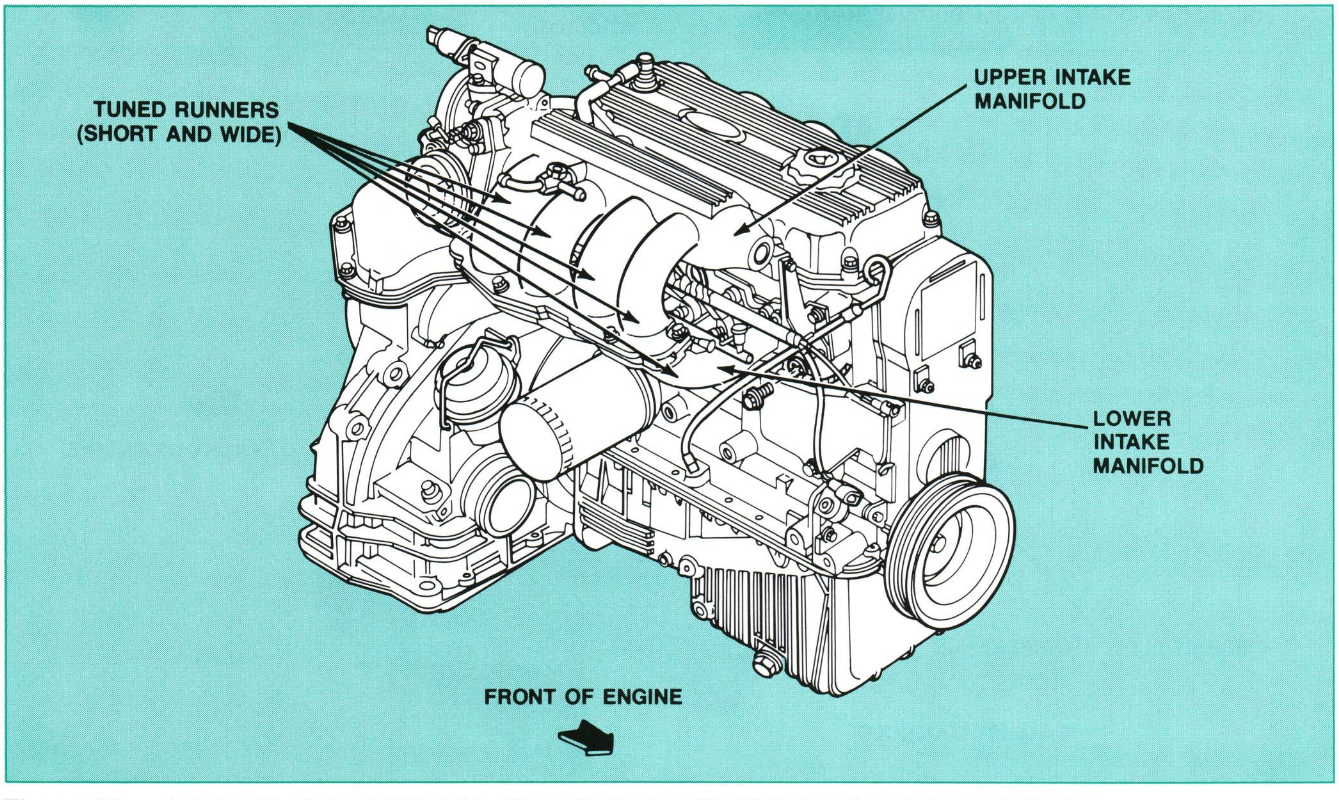

TUNED RUNNERS (SHORT AND WIDE)
UPPER INTAKE MANIFOLD
LOWER INTAKE MANIFOLD
FRONT OF ENGINE

Figure 92 — Intake Tuning: 1987 1.9L, Four-Cylinder, Multi-Point Fuel-Injected Engine

EXHAUST MANIFOLD

DESCRIPTION

The exhaust manifold guides the exhaust gases from the cylinder head to the exhaust system. In-line engines usually have one exhaust manifold, while V-6 and V-8 engines have two exhaust manifolds.

MATERIALS

Cast Iron

As noted for intake manifolds, cast iron is cheap and easy to machine, but heavy.

Cast Nodular Iron

As discussed under "Crankshaft," nodular iron is stronger and more durable than conventional cast iron. Manifolds can be made lighter with nodular iron, because its strength allows less material to be used. The disadvantage of nodular iron is that it is difficult to machine.

Fabricated Steel

Fabricated steel is lighter than iron and is easier to assemble into tubes for tubular headers. Unfortunately, steel is also more costly than either conventional cast iron or cast nodular iron.

DESIGN

Tuned Exhaust Manifolds

Exhaust manifolds can be tuned in a way similar to the tuning of intake manifolds. Proper tuning of the exhaust manifold tubes can actually create a vacuum that helps to suck exhaust gases out of the exhaust system (Fig. 94), improving volumetric efficiency.

Separate, tuned exhaust headers can also improve efficiency by preventing exhaust flow from one cylinder from interfering with the exhaust flow from another cylinder. Cylinders next to one another may release exhaust gas at about the same time. When this happens, the pressure of the exhaust gas from one cylinder may interfere with the flow from the other cylinder (Fig. 93). With separate headers, the cylinders are isolated from one another, interference is eliminated, and the engine breathes better. The problem of interference is especially common with V-8 engines (Fig. 93), because they have a lot of cylinder overlap. V-6 engines have less cylinder overlap.

Four-cylinder engines often have an exhaust overlap problem with the first and second or third and fourth cylinders (Fig. 95). While the overlap is usually not as severe as with a V-8 engine, the problems caused can be bad, because half of the engine's cylinders are affected.

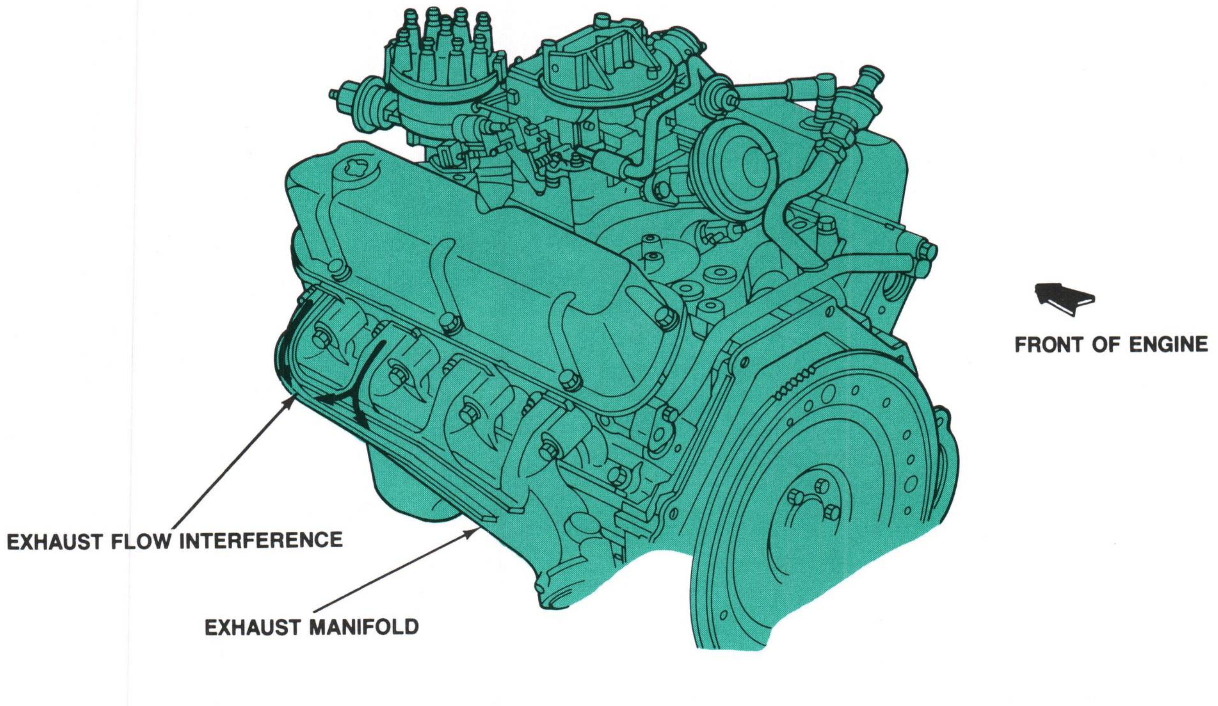


Figure 93 — Cylinders Interfering with Each Other's Exhaust Flow

EXHAUST MANIFOLD

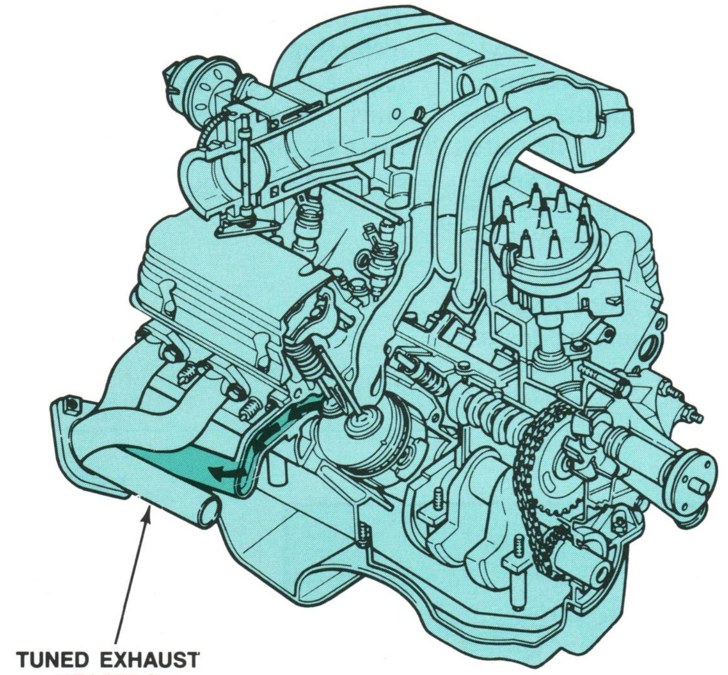

TUNED EXHAUST
HEADERS

Figure 94 — Tuned Exhaust Headers: 1987 5.0L V-8 Engine

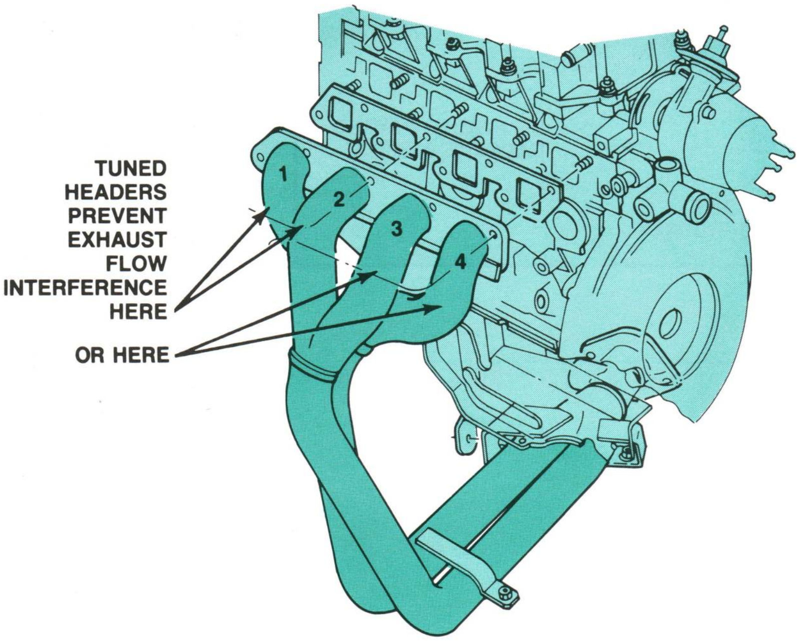

TUNED
HEADERS
PREVENT
EXHAUST
FLOW
INTERFERENCE
HERE
OR HERE
1
2
3
4

Figure 95 — Tuned Exhaust Headers: 1987 1.9L Four-Cylinder Engine

SPECIAL INNOVATIONS

BALANCE SHAFTS

Twin balance shafts are used to correct the instability and vibration of an undersquare bore/stroke, four-cylinder engine at higher RPMs. These counter-rotating iron shafts, located in a housing beneath the crankshaft, rotate at twice the engine speed. They are designed to correct the problem of secondary vibration. (Secondary vibration is vibration at twice the frequency of the primary, or crankshaft speed). The balance shafts are chain driven from the crankshaft, and are also designed to pump oil away from the shaft housing, thus lowering engine oil pumping losses (Fig. 96).

LOW DRAG OIL AND WATER PUMPS

The more recent innovations in oil and water pump technology have produced efficient designs that require less engine power to operate them than older units. These designs help the overall fuel economy ratings of an engine, without losing pump effectiveness (Fig. 97).

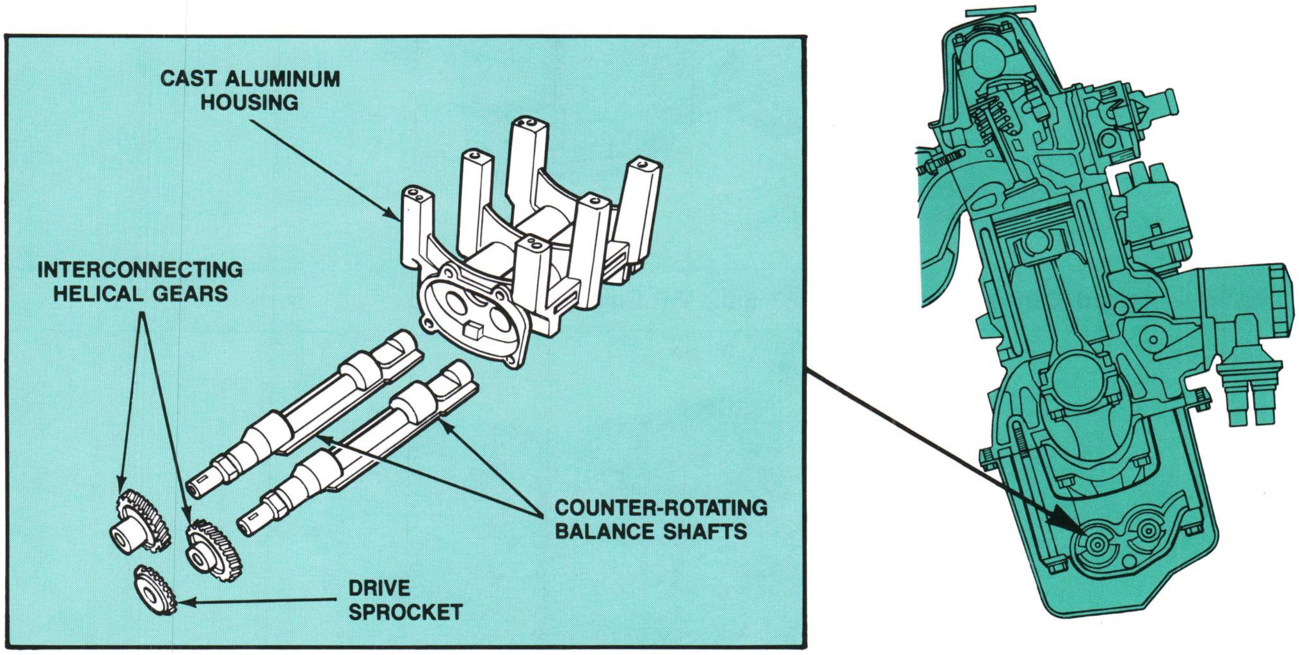
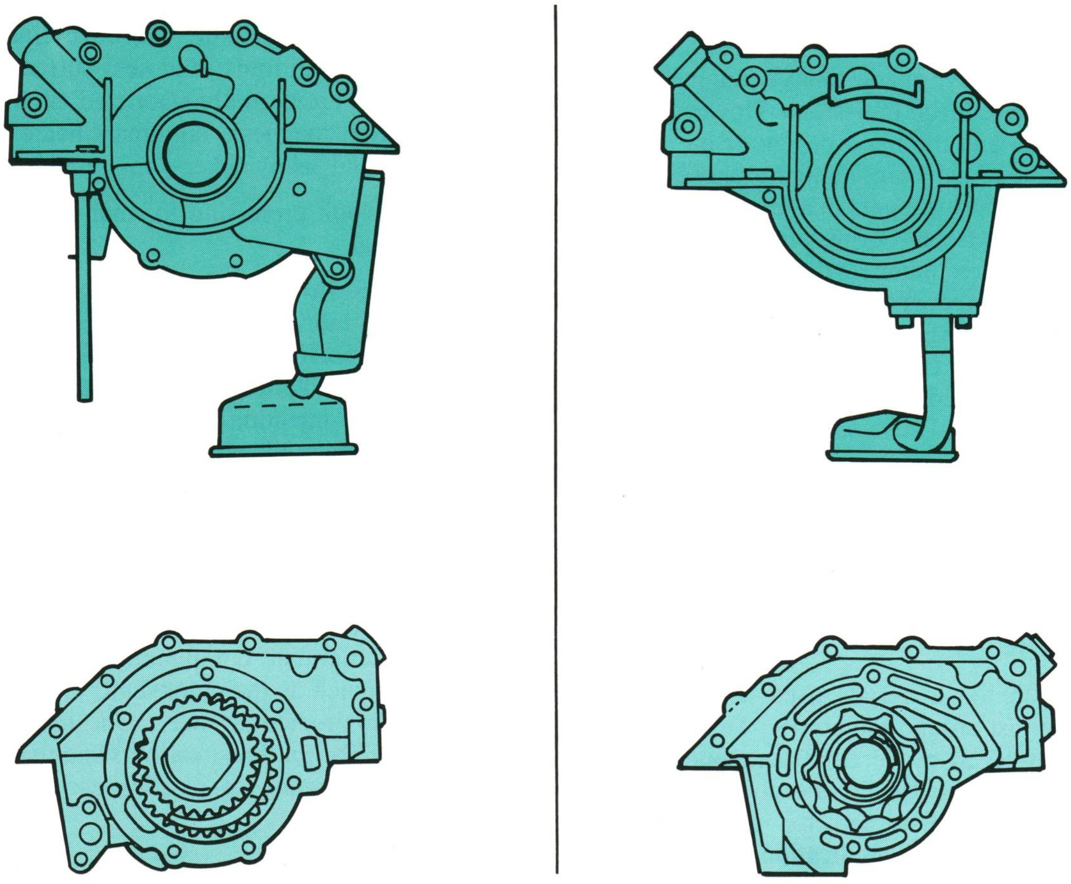

CAST ALUMINUM HOUSING
INTERCONNECTING HELICAL GEARS
COUNTER-ROTATING BALANCE SHAFTS
DRIVE SPROCKET

Figure 96 — Balance Shafts



STANDARD OIL PUMP DESIGN

LOW-FRICTION OIL PUMP DESIGN

Figure 97 — Example of Design Change — Less Drag Oil Pump

NEW ENGINE MATERIALS AND TECHNOLOGY

INTRODUCTION: IMPROVING THE STANDARD DESIGN

The different materials and design features discussed so far in this book have made today's engines more efficient and have reduced emissions. However, both the materials used and the basic design of the current automobile engine remain very similar to those used in years past. Some improvements that are being worked on now continue this trend. For instance, we may soon see air-filled chambered dampers used instead of valve springs. The air chamber (Fig. 98) is a perfect natural progressive-rate spring. Each time its volume is cut in half, its pressure approximately doubles. The farther open the valve is pushed, the more return pressure is increased.

In addition to improvements in the standard engine design and materials, some truly new developments in both materials and design are in progress. Some of these developments may see production soon, while others are still "on the drawing board."

NEW MATERIALS

Major changes in the materials used in automobile engines may be just around the corner. Tests are currently being run on many ceramic components, and ceramics are already in use for diesel engines (Fig. 99). Ceramics have high strength for reliability, high thermal expansion for easy application to component surfaces, and great resistance to wear. They have good insulation qualities, so they can serve as coatings and inserts for pistons, cylinder liners, cylinder heads, valves, lifters, manifolds, and seal surfaces. Among these materials are partially stabilized zirconia (PSZ), silicon carbide, magnesia alumina silicate, fused silica, syalon, and many other compounds.

Plastics also look promising for many parts currently made of metal.

One small U.S. firm has produced several engines that use a graphite fabric and epoxy composite (CYCOM) for the block material (Fig. 100). Most of the moving parts are made of Torlon, a heat resistant plastic material that can be injection molded and mass produced easily. These materials are lightweight and heat resistant, and they show some promise for lowering production costs and increasing mechanical efficiency.

Since most of the engine operates at about 100°C (212°F), plastic parts that can withstand up to 500 degrees are used whenever possible in the engine. The combustion chamber components and high torque components (such as the crankshaft) are still made of an alloy or high-strength steel. One manufacturer is already using Torlon thrust washers and this appears to be just the beginning of plastics use in production engines.

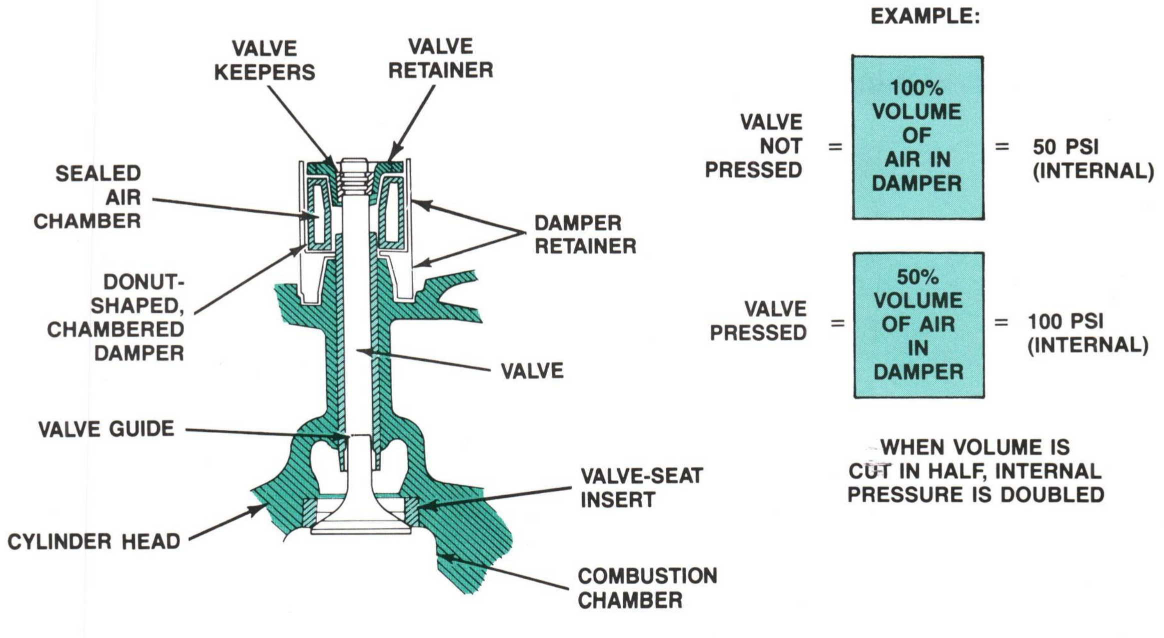

VALVE KEEPERS
VALVE RETAINER
SEALED AIR CHAMBER
DAMPER RETAINER
DONUT-SHAPED, CHAMBERED DAMPER
VALVE
VALVE GUIDE
VALVE-SEAT INSERT
CYLINDER HEAD
COMBUSTION CHAMBER
EXAMPLE:
VALVE NOT PRESSED
=
100% VOLUME OF AIR IN DAMPER
=
50 PSI (INTERNAL)
VALVE PRESSED
=
50% VOLUME OF AIR IN DAMPER
=
100 PSI (INTERNAL)
WHEN VOLUME IS CUT IN HALF, INTERNAL PRESSURE IS DOUBLED

Figure 98 — Compressed Air Return Damper for Valves

NEW ENGINE MATERIALS AND TECHNOLOGY

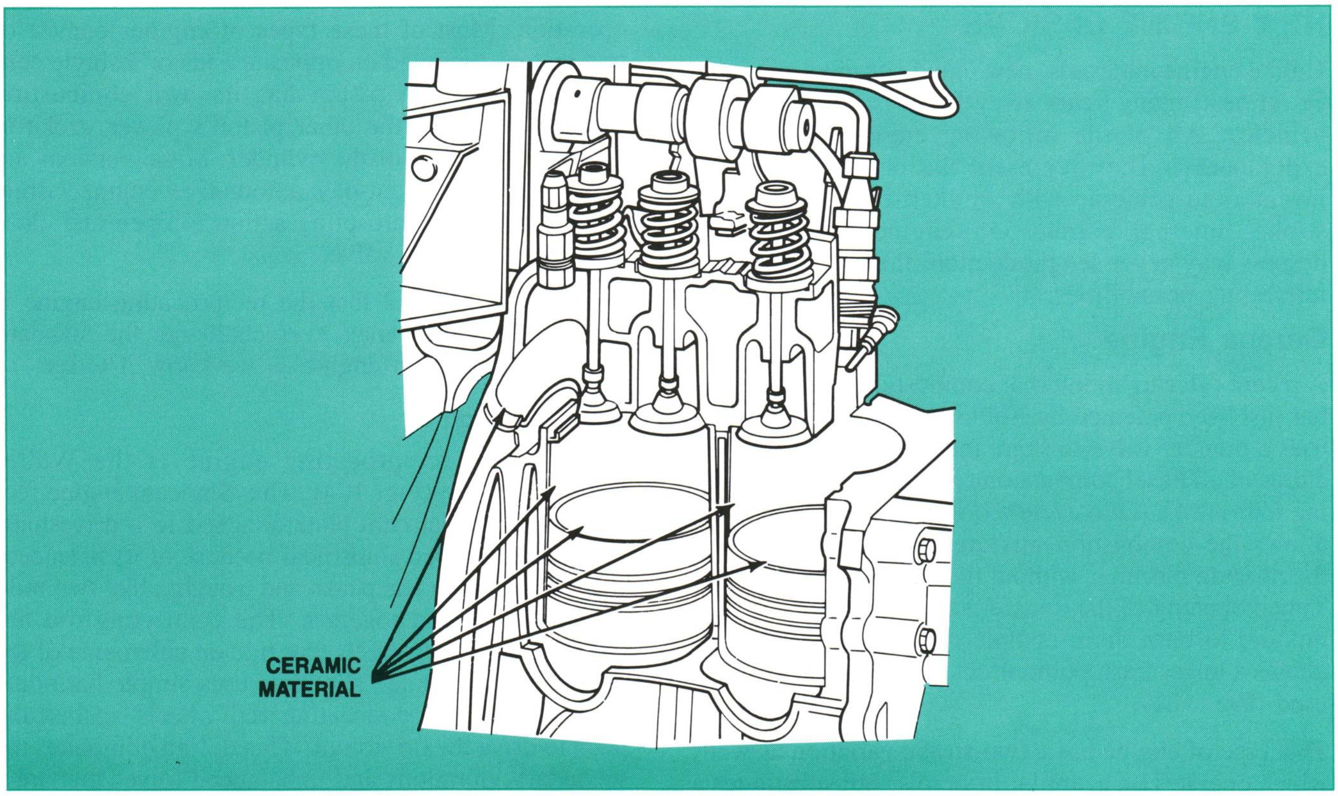

CERAMIC MATERIAL

Figure 99 — Use of Ceramics in Current Diesel Engine

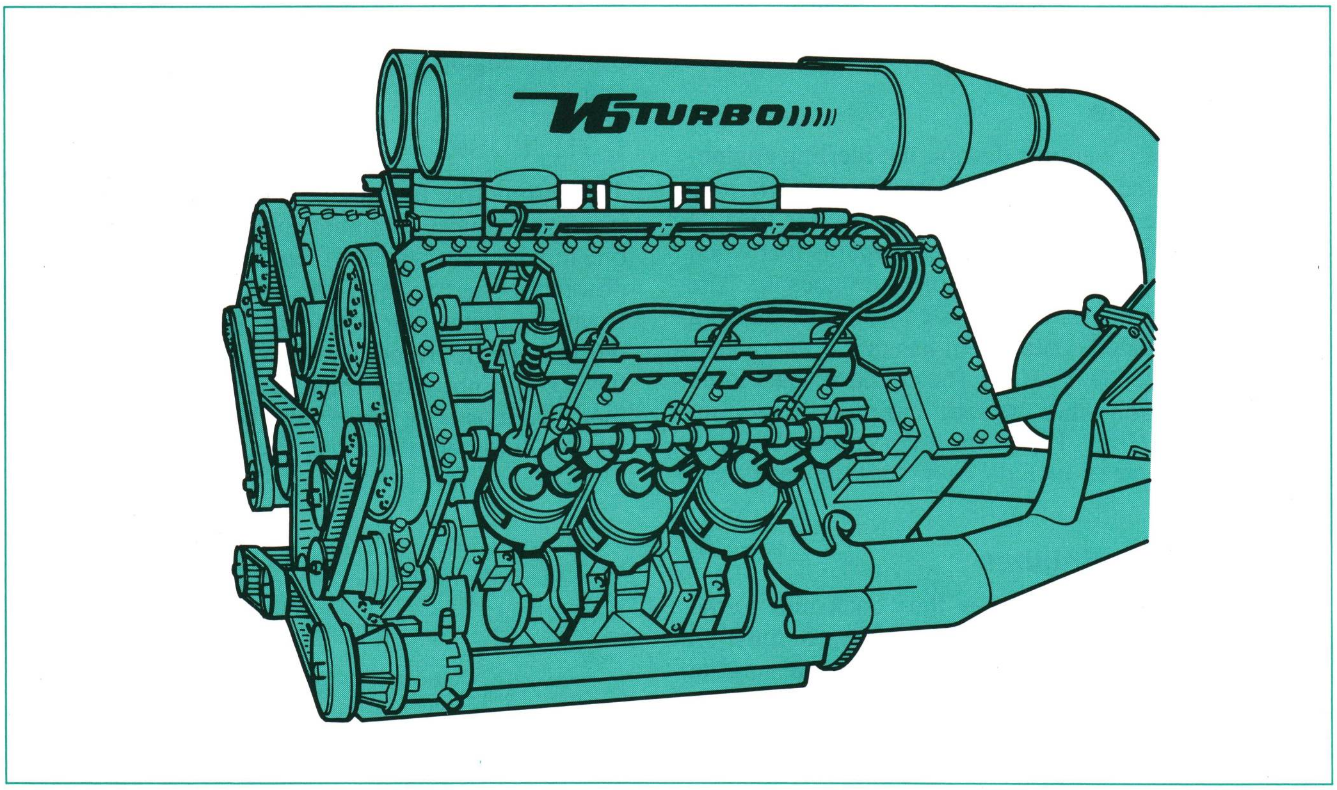


Figure 100 — Plastic Engine

NEW ENGINE MATERIALS AND TECHNOLOGY

NEW ENGINE DESIGNS

Unlike engine materials, new engine designs appear to be (at best) many years away from use in production vehicles. All of the following engine designs are experimental. They represent the ongoing effort by inventors to come up with an alternative to the four-stroke, internal combustion engine. While these designs may never see production, they do offer some interesting possibilities.

Gerace Engine

A recent offering in internal combustion engine design has just been patented by Anthony Gerace. The engine uses a transfer valve to share the compression temperatures of a Diesel combustion chamber with an adjoining four-stroke (Otto cycle) combustion chamber. This allows the combustion mixture to preheat and starts the mixture burning, without the need of a spark plug. Timed opening of the transfer valve allows the air/fuel mixture to burn more completely and efficiently and allows a lower flash point or octane rating of fuel to be used (Fig. 101).

This type of engine has a two-stroke variation as well, which operates on a similar principle, but substitutes a two-cycle cylinder for the Diesel cylinder. This version requires two crankshafts and a special two-to-one drive ratio as well as a two-to-one stroke relationship between cylinders (Fig. 102).

Sterling Engine

Another alternative engine design, the Sterling engine, has been around for many years. In fact, it was invented before the four-stroke engine used in today's automobiles. Its basic operating principle is that when gas in a container is heated, the pressure goes up. The pressure goes down as the gas is cooled. The Sterling engine uses a sealed container of gas that is alternately heated and cooled (Fig. 103). The container puts force on a power piston when heated, and pulls it back up when cooled (Fig. 103). In theory, the Sterling engine's advantages include easy starting and silent running.

Reciprocating Engines

The reciprocating engine uses the "back and forth" movement of pistons in two opposing combustion chambers for two-stroke or four-stroke engine operation. Most of these types of engines consist of two pistons mounted on opposite ends of a single connecting rod. Each piston has its own combustion chamber and uses the other piston's power stroke to return it to the top of the cylinder. Some versions are valved like a present-day automotive engine, while others use the reciprocating action to open and close an air/fuel mixture valve.

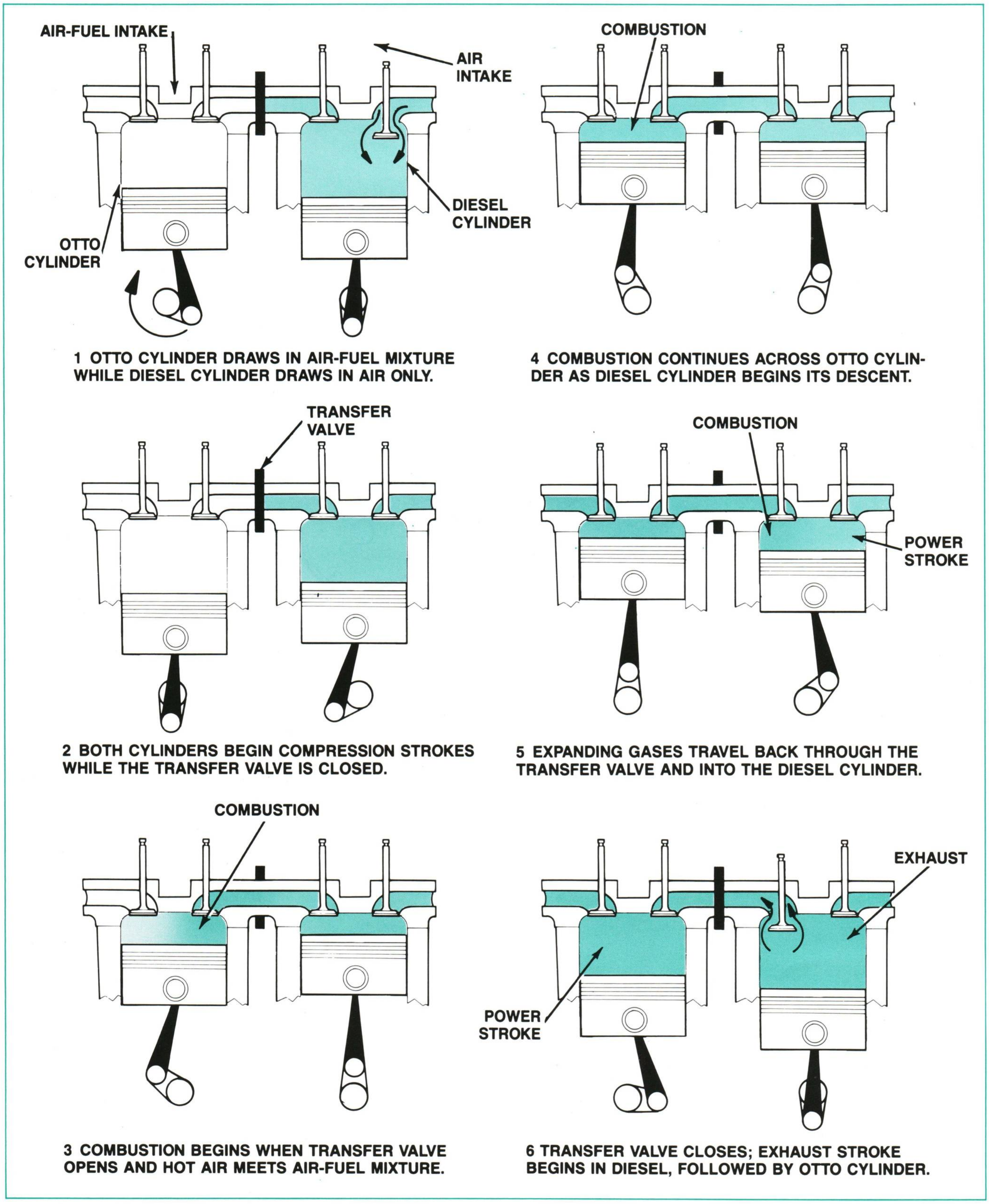
Some engineers feel that the reciprocating engine is the only type that may ever challenge the standard internal combustion engine as we know it today.

Sinocam Engine

One type of reciprocating engine is the Waller Sinocam engine (Fig. 104). This Sinocam engine features a sinusoidal cam plate attached to a driveshaft. This plate is called sinusoidal because of its balanced, wavy profile that has peaks and troughs, like two mild sine waves linked together. The connecting rod has two small contact wheels that ride on either side of the sinusoidal cam plate. The plate uses simple harmonic movement of the connecting rod wheels against the plate to drive the driveshaft. This design eliminates the secondary vibrations and imbalanced forces that are a problem in conventional engines. The inventors claim that there are twice as many power output "pulses" per cycle as in conventional automobile engines. The Sinocam engine is designed to be small, lightweight, and efficient.

CONCLUSION

The automotive internal combustion engine has been improved almost continuously since its invention over one hundred years ago. Today's engines produce more power for their weight, use less fuel, and emit fewer harmful exhaust gases than past engines did. Yet, it is worthwhile to remember that these improvements have come not from radical new designs, but from modifications to a very sound basic design: the four-stroke, automotive internal combustion engine.


AIR-FUEL INTAKE
AIR INTAKE
DIESEL CYLINDER
OTTO CYLINDER
TRANSFER VALVE
COMBUSTION
COMBUSTION
COMBUSTION
POWER STROKE
EXHAUST
POWER STROKE

1 OTTO CYLINDER DRAWS IN AIR-FUEL MIXTURE WHILE DIESEL CYLINDER DRAWS IN AIR ONLY.

2 BOTH CYLINDERS BEGIN COMPRESSION STROKES WHILE THE TRANSFER VALVE IS CLOSED.

3 COMBUSTION BEGINS WHEN TRANSFER VALVE OPENS AND HOT AIR MEETS AIR-FUEL MIXTURE.

4 COMBUSTION CONTINUES ACROSS OTTO CYLINDER AS DIESEL CYLINDER BEGINS ITS DESCENT.

5 EXPANDING GASES TRAVEL BACK THROUGH THE TRANSFER VALVE AND INTO THE DIESEL CYLINDER.

6 TRANSFER VALVE CLOSES; EXHAUST STROKE BEGINS IN DIESEL, FOLLOWED BY OTTO CYLINDER.

Figure 101 — Gerace Four-Cycle Engine

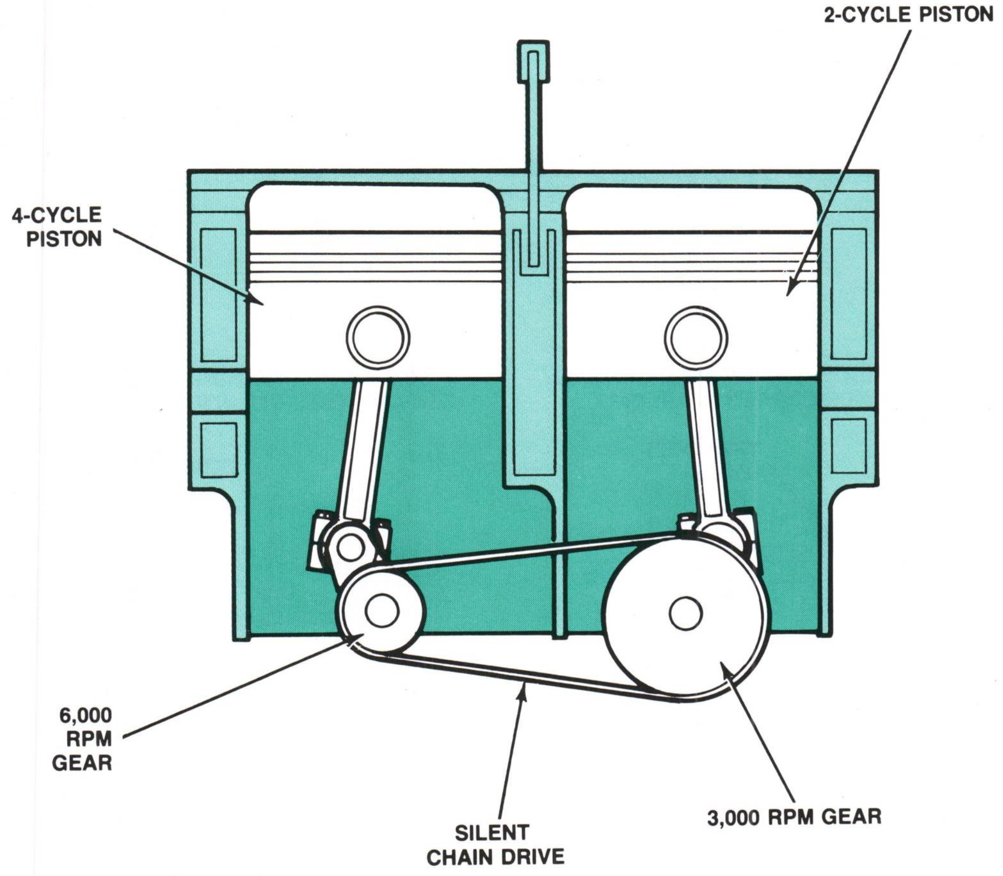

2-CYCLE PISTON
4-CYCLE PISTON
6,000 RPM GEAR
SILENT CHAIN DRIVE
3,000 RPM GEAR

Figure 102 — Gerace Compound-Cycle Engine

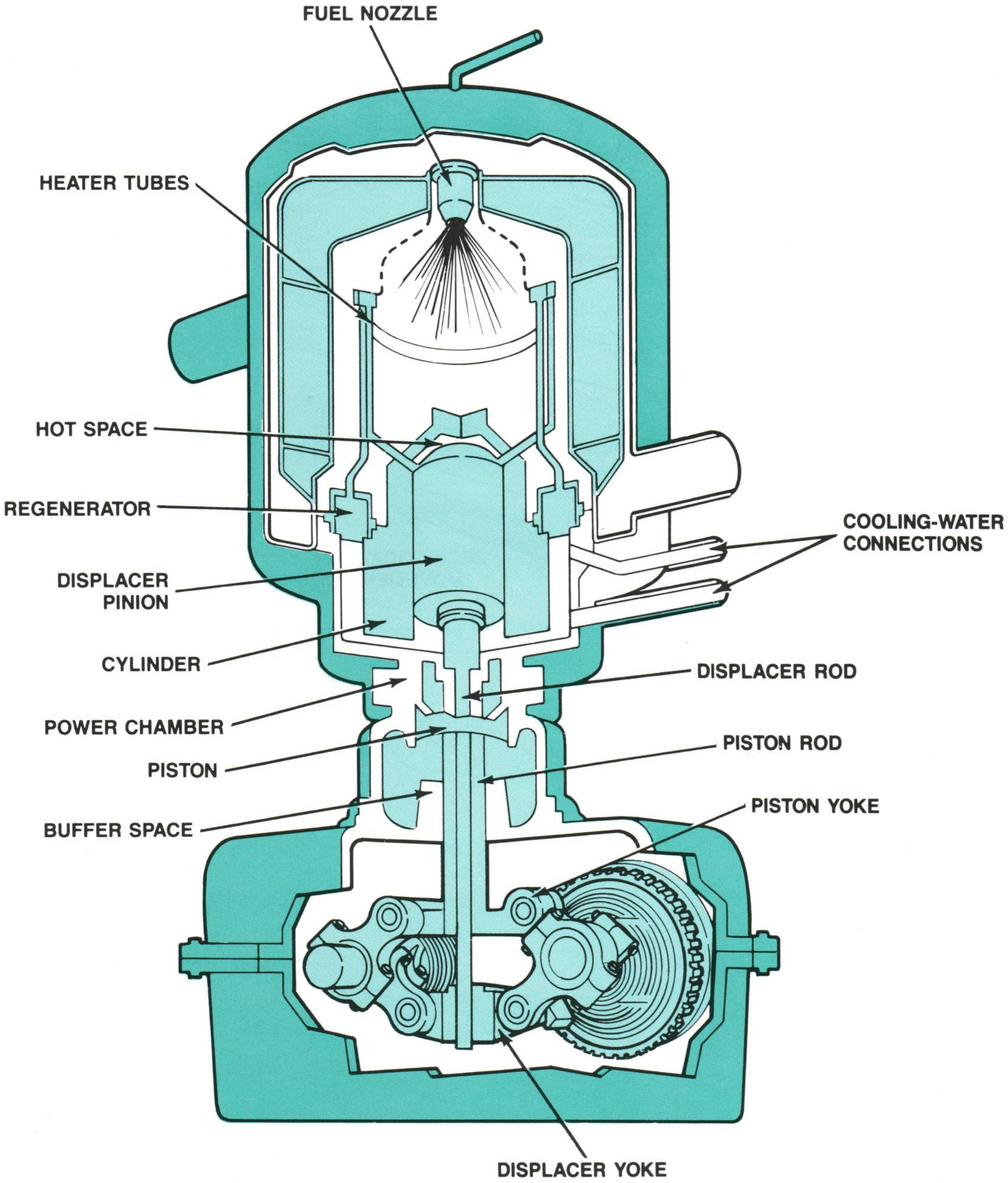

FUEL NOZZLE
HEATER TUBES
HOT SPACE
REGENERATOR
DISPLACER PINION
CYLINDER
POWER CHAMBER
PISTON
BUFFER SPACE
COOLING-WATER CONNECTIONS
DISPLACER ROD
PISTON ROD
PISTON YOKE
DISPLACER YOKE

Figure 103 — Sterling Engine Cutaway

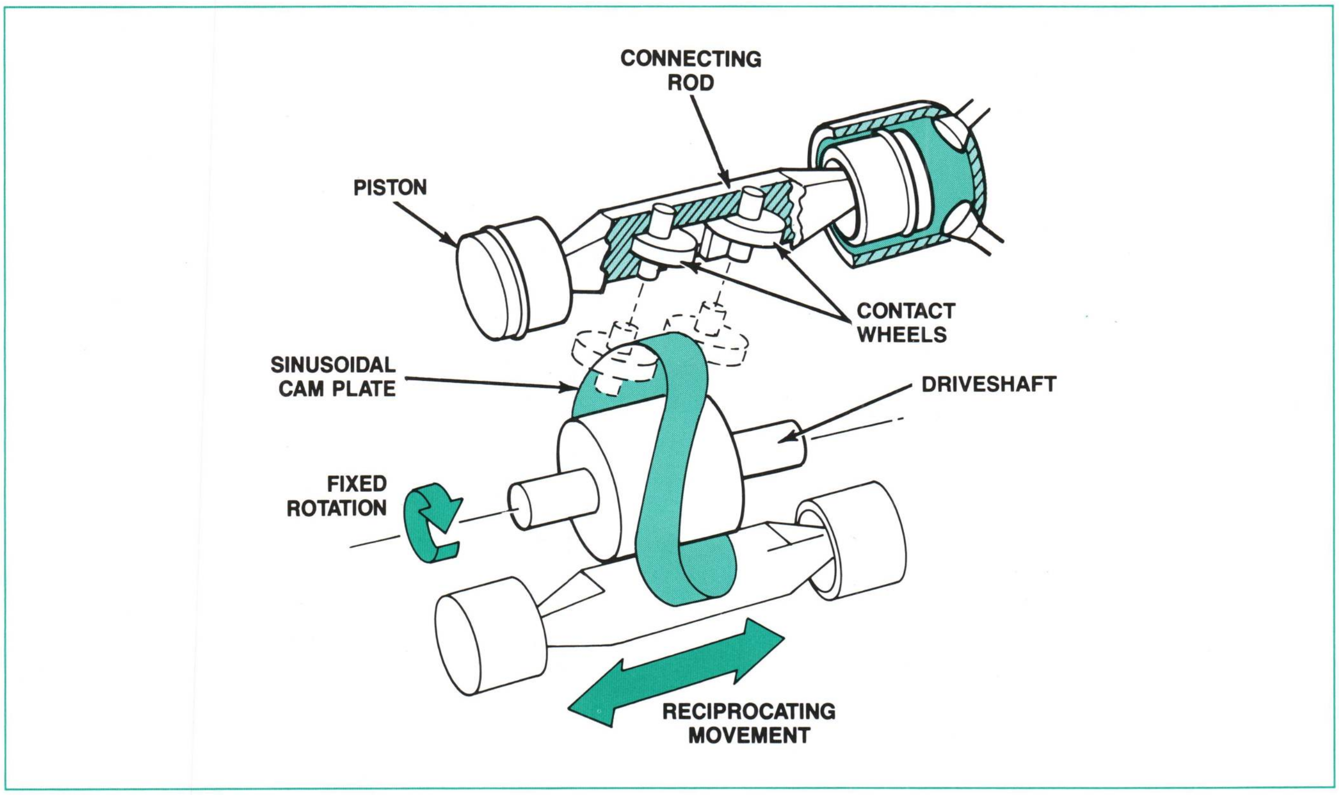

CONNECTING ROD
PISTON
CONTACT WHEELS
SINUSOIDAL CAM PLATE
DRIVESHAFT
FIXED ROTATION
RECIPROCATING MOVEMENT

Figure 104 — Sinocam Engine

GLOSSARY

AIR/FUEL RATIO — The ratio between the air and fuel contained in the mixture; measured by weight or volume.

ALLOY — A mixture of different metals. For example, solder is an alloy of lead and tin.

ALUMINUM — A metal noted for its lightness and often combined with small quantities of other metals for automotive use.

ATDC — After Top Dead Center.

AXIAL — The direction parallel to the bearing bore or shaft.

BACK-PRESSURE — A resistance to free flow, such as a restriction in the exhaust line.

BASE CIRCLE — The lowest area of the cam lobe directly opposite from the nose arc.

BBDC — Before Bottom Dead Center.

BDC — Bottom Dead Center.

BEARING — A part in which a journal, pivot or the like turns or moves.

BEARING CLEARANCE — The amount of space for oil to flow between the fillet or journal and bearing surface.

BLOCK — The main casting of the engine that contains the pistons and cylinders.

BORE — The diameter of a hole, such as a cylinder; also, to enlarge a hole with a cutting tool.

BOSS — An extension or strengthened section, such as the projections within a piston which support the piston pin or piston pin bushings.

BTDC — Before Top Dead Center.

BUSHING — A removable line for a bearing.

BYPASS — An alternate path for a flowing substance.

CAM GROUND PISTON — A piston ground to a slightly oval shape which, under the heat of operation, becomes round.

CAM LOBES — See "lobes."

CAM PROFILE — Shape of cam lobe, used to determine duration and lifter type.

CAMSHAFT — The shaft containing egg-shaped lobes used to operate the engine valves.

CAMSHAFT SUPPORTS — Brackets placed on the cylinder head to support the camshaft in overhead cam engines.

CARBON — A common non-metallic element which is an excellent conductor of electricity. It also forms in the combustion chamber of an engine during the burning of fuel and lubricating oil.

CASTING — A part produced by pouring melted metal into a mold and then cooling it so that it shapes to the mold.

CHROMIUM — A hard metallic element that resists corrosion and wears well when used as a coating for piston rings.

CHROMIUM STEEL — An alloy of steel with a small amount of chromium to produce a metal which is highly resistant to oxidation and corrosion.

CLEARANCE — The space allowed between two parts, such as between a journal and a bearing.

COMBUSTION — The chemical reaction between air and fuel when a spark is applied. This reaction produces heat and gases as a result.

COMBUSTION CHAMBER — The volume of the cylinder above the piston with the piston at top dead center.

COMPOUND — A mixture of two or more ingredients.

COMPRESSION — The reduction in volume or the "squeezing" of a gas. As applied to metal, such as a coil spring, compression is the opposite of tension.

COMPRESSION RATIO — The volume of the combustion chamber at the end of the compression stroke as compared to the volume of the cylinder and chamber with the piston at bottom dead center.

COMPRESSION RINGS — The upper rings on a piston designed to hold the compression in the cylinder.

COMPRESSION STROKE — The piston stroke from BDC to TDC during which both valves are closed and the gases in the cylinder are compressed.

CONNECTING ROD — A rod that connects the piston to the crankshaft.

COOLANT — The liquid that circulates in an engine cooling system.

CRANKCASE — The housing within which the crankshaft and many other parts of the engine operate.

CRANKSHAFT COUNTERBALANCE — A series of weights attached to or forged integrally with the crankshaft and so placed as to offset the reciprocating weight of each piston and rod assembly.

GLOSSARY

CYLINDER — A round hole having some depth bored to receive a piston; also sometimes referred to as "bore."

CYLINDER BLOCK — The largest single part of an engine. The basic or main mass of metal in which the cylinders are bored or placed.

CYLINDER HEAD — A detachable portion of an engine fastened securely to the cylinder block which contains all or a portion of the combustion chamber.

CYLINDER SLEEVE — A liner or tube interposed between the piston and the cylinder wall or cylinder block to provide a readily renewable wearing surface for the cylinder.

DEAD CENTER — The extreme upper or lower position of the crankshaft throw at which the piston is not moving in either direction.

DENSITY — Compactness; relative mass of matter in a given volume.

DETONATION — As used in an automobile, indicates a too-rapid burning or explosion of the mixture in the engine cylinders. It becomes audible through a vibration of the combustion chamber walls and is sometimes called "ping" or spark knock.

DISTORTION — A warpage or change in form from the original shape.

DOUBLE OVERHEAD CAM — An engine having two camshafts placed in the cylinder head for more direct opening of the valves with less friction.

ENGINE DISPLACEMENT — The sum of the displacement of all the engine cylinders. See "piston displacement."

EXHAUST MANIFOLD — The part of an engine through which exhausted or spent gases flow to the exhaust system.

EXPANSION — An increase in volume. For example, when a metal rod is heated it increases in length and perhaps also in diameter; expansion is the opposite of contraction.

FAST BURN — Using high compression and swirl, the rapid combustion of an air/fuel mixture.

FATIGUE — The eventual breakdown of material due to continued loading and unloading.

FILLET — A rounded filling between two parts joined at an angle.

FLOATING PISTON PIN — A piston pin which is not locked in the connecting rod or the piston, but is free to turn or oscillate in both the connecting rod and the piston.

"FLUTTER" OR "BOUNCE" — A condition where the valve is not held tightly on its seat during the time the cam is not lifting it.

FLYWHEEL — A heavy wheel in which energy is absorbed and stored by means of momentum.

FOLLOWER — A component that "follows" or rides on the camshaft, and is used to open a valve directly.

FORGED ALLOY STEEL — A mixture of materials with steel that has greater strength than cast iron.

FOUR-CYCLE ENGINE — Also known as Otto cycle engine. Combustion occurs every other revolution of the crankshaft; a cycle being considered as 1/2 revolution of the crankshaft. These cycles or strokes are: (1) intake stroke; (2) compression stroke; (3) power stroke; (4) exhaust stroke.

FRICTION — The resistance to movement between two parts when they are joined together.

FULCRUM — The support on which a lever turns to move a body.

GASKET — A substance placed between two metal surfaces to act as a seal.

GEAR REDUCTION — Ratio between gears that allows one gear to travel at a greater or lesser speed than another.

HARMONIC BALANCER — A device to reduce the torsional or twisting vibration which occurs along the length of the crankshaft used in multiple cylinder engines. Also known as a vibration damper.

HYDROCARBON — Any compound composed entirely of carbon and hydrogen, such as petroleum products.

INLET VALVE OR INTAKE VALVE — A valve which permits a fluid or gas to enter a chamber and seals against exit.

IN-LINE ENGINE — Engine having all cylinders arranged in a single, straight row.

INTAKE MANIFOLD — The tube used to conduct the air or air/fuel mixture to the engine cylinders.

GLOSSARY

INTEGRAL — Part of a single unit or component.

JOURNAL — The part of a shaft that turns in a bearing.

KNOCK — A general term used to describe various noises occurring in an engine; may be used to describe noises made by loose or worn mechanical parts, pre-ignition, detonation, etc.

LEAN BURN — Combustion that occurs with more air than required to fully consume the mixture.

LIFTER — A component that rides on the camshaft and lifts a push rod or rocker arm, that, in turn, opens the valve.

LINER — Usually a thin section placed between two parts, such as a replaceable cylinder liner in an engine.

LOBES — Egg-shaped surfaces of hardened steel on the camshaft that are used to open and close the valves.

LOW FORCE COMPRESSION VALVE SPRING — This type of valve spring needs less pressure to compress the spring and open the valve. Usually found on engines with low lift camshafts and used to keep friction losses to a minimum.

LUBRICANT — Substance that reduces friction between mechanical parts.

MANIFOLD — A pipe with multiple openings used to connect various cylinders to one inlet or outlet.

MISFIRING — Failure of ignition to occur in one or more cylinders while the engine is running; may be continuous or intermittent failure.

MOLYBDENUM — Soft chemical element added to alloy materials to give higher strength and better wear.

NEEDLE BEARING — An anti-friction roller bearing using long, small diameter rollers.

OCTANE NUMBER — A unit of measurement on a scale intended to indicate the tendency of a fuel to resist detonation or knock.

OIL GALLERIES — Passageways in the cylinder block for pumping lubrication to the components.

OTTO CYCLE — Also called four-stroke cycle. Named after the man who adopted the principle of four cycles of operation for each explosion in an engine cylinder. They are: (1) intake stroke, (2) compression stroke, (3) power stroke, (4) exhaust stroke.

OVERHEAD CAM ENGINE — Engine having a single camshaft placed in the head for more direct opening of the valves.

OVERHEAD VALVE OR VALVE-IN-HEAD ENGINE — An engine design having valves located in the cylinder head directly above the pistons.

OVERSQUARE — A relationship between the bore and stroke where the bore is larger than the stroke.

OXIDES OF NITROGEN (NO_x) — A compound formed during the engine's combustion process when oxygen in the air combines with nitrogen in the air to form nitrogen oxides: the agents in photochemical smog.

PISTON — A cylindrical part closed at one end which is connected to the crankshaft by the connecting rod. The force of the explosion in the cylinder is exerted against the closed end of the piston, causing the connecting rod to move the crankshaft.

PISTON COLLAPSE — A condition describing a collapse or a reduction in diameter of the piston skirt due to heat or stress.

PISTON DISPLACEMENT — The volume of air moved or displaced by moving the piston from one end of its stroke to the other.

PISTON DOME — The shape of the piston top, which serves as the base of the combustion chamber.

PISTON HEAD — That part of the piston above the rings.

PISTON LANDS — Those parts of a piston between the piston rings.

PISTON PIN — The journal for the bearing in the small end of an engine connecting rod which also passes through piston walls. Also known as a wrist pin.

PISTON RING — An expanding ring placed in the grooves of the piston to provide a seal to prevent the passage of fluid or gas past the piston.

PISTON RING EXPANDER — A spring placed behind the piston ring in the groove to increase the pressure of the ring against the cylinder wall.

PISTON RING GAP — The clearance between the ends of the piston ring.

PISTON RING GROOVE — The channel or slots in the piston in which the piston rings are placed.

PISTON SLAP — A condition where excess clearance between the piston and cylinder wall causes the piston to strike the wall.

GLOSSARY

PISTON SKIRT — That part of the piston below the rings.

POPPET VALVE — A valve structure consisting of a circular head with an elongated stem attached in the center which is designed to open and close a circular hole or port.

PORT — In engines, the openings in the cylinder block for valves, exhaust inlet pipes, or water connections. In two-cycle engines, the openings for inlet and exhaust purposes.

POSITIVE VALVE ROTATORS — Devices that turn the valves approximately 3 degrees per valve lift to equalize wear on the valve and seat.

PRE-COMBUSTION CHAMBER — A small chamber or area where combustion begins in a stratified charge combustion chamber.

PRE-IGNITION — Ignition occurring earlier than intended. For example, the explosive mixture being fired in a cylinder as by a flake of incandescent carbon before the electric spark occurs.

PURGE — Removal of gases or liquid from a cylinder or confined space.

PUSH ROD — A connecting link in an operating mechanism, such as the rod interposed between the valve lifter and rocker arm on an overhead valve engine.

QUENCH — To cool a surface area or mixture.

RATIO — The relation or proportion that one number bears to another.

RECIPROCATING — A back and forth movement, such as the action of a piston in a cylinder.

RELIEF — The amount one surface is set below or above another surface.

REVOLUTION — A full turn of 360 degrees.

ROCKER ARM — In an automobile engine, this is a lever located on a fulcrum or shaft, one end of the lever being on the valve stem, the other being on the push rod.

ROLLER BEARING — An inner and outer race upon which hardened steel rollers operate.

ROLLER CAM — Specially hardened and profiled cam used especially with roller-type lifters.

ROLLER HYDRAULIC LIFTERS — Lifters with rollers placed at the base to limit lifter/cam friction.

SCORE — A scratch, ridge or groove marring a finished surface.

SEAT — A surface, usually machined, upon which another part rests or seats; for example, the surface upon which a valve face rests.

SPARK KNOCK — Same as "pre-ignition."

SQUARE — A relationship between the bore and the stroke when the bore is the same dimension as the stroke.

STAMPING — A piece of sheet metal cut and formed into the desired shape with the use of dies.

STRESS — The force or strain to which a material is subjected.

STROKE — In an automobile engine, the distance moved by the piston, from Top Dead Center to Bottom Dead Center.

SURFACE QUENCH — A condition where the surface area of a combustion chamber cools the air/fuel mixture, restricting combustion.

SURFACE-TO-VOLUME RATIO — The ratio between the surface area of the combustion chamber and the volume of the combustion chamber when the piston is at TDC.

TAPPET — The adjusting screw for varying the clearance between the valve stem and the cam. May be built into the valve lifter in an engine or may be installed in the rocker arm on an overhead valve engine.

TDC — Top Dead Center.

THERMAL EFFICIENCY — A gallon of fuel contains a certain amount of potential energy in the form of heat when burned in the combustion chamber. Some of the heat is lost and some is converted into power. The thermal efficiency is the ratio of work accomplished compared to the total quantity of heat contained in the fuel.

THROW — With reference to an automobile engine, the distance from the center of the crankshaft main bearing to the center of the connecting rod journal.

TIMING CHAIN — Chain used to drive camshaft and accessory shafts of an engine.

TIMING GEARS — Any group of gears which are driven from the engine crankshaft to cause the valves, ignition and other engine driven apparatus to operate at the desired time during the engine cycle.

TOLERANCE — A permissible variation between the two extremes of a specification of dimensions.

GLOSSARY

TORQUE — An effort devoted toward twisting or turning.

UNDERSQUARE — A relationship between the bore and stroke where the bore is smaller than the stroke.

VALVE — A device for opening and sealing an aperture.

VALVE CLEARANCE — The air gap allowed between the end of the valve stem and the valve lifter or rocker arm to compensate for expansion due to heat.

VALVE CANTING — The non-parallel placement of valves in a cylinder head.

VALVE CURTAIN — The opening of the annular passage between the valve and its seat when the valve is fully open.

VALVE DURATION — The length of time that a valve is open, measured in degrees.

VALVE FACE — That part of a valve which mates with and rests upon a seating surface.

VALVE GUIDE — See "valve stem guide."

VALVE HEAD — The portion of the valve upon which the valve face is machined.

VALVE-IN-HEAD ENGINE — Same as overhead valve engine.

VALVE LIFT — The height that the valve travels when fully open.

VALVE LIFTER — A push rod or plunger placed between the cam and the valve on an engine; is often adjustable to vary the length of the unit.

VALVE OVERLAP — An interval expressed in degrees where both valves of an automobile engine cylinder are open at the same time.

VALVE ROTATORS — See "positive valve rotators."

VALVE SEAL — A device placed on the valve stem or guide to prevent excess oil from seeping into the clearance between the valve stem and valve guide.

VALVE SEAT — The matched surface upon which the valve face rests.

VALVE SPRING — A spring attached to a valve to return it to the seat after it has been released from the lifting or opening means.

VALVE STEM — That portion of a valve which rests within a guide.

VALVE STEM GUIDE — A bushing or hole in which the valve stem is placed which allows lateral motion only.

VALVE TRAIN — All components used between the camshaft and valve. Used to open each valve.

VIBRATION DAMPER — A device to reduce the torsional or twisting vibration which occurs along the length of the crankshaft used in multiple cylinder engines. Also known as a harmonic balancer.

VOLUME — The measure of space expressed as cubic inches, cubic feet, etc.

VOLUMETRIC EFFICIENCY — A comparison between the ideal and actual air breathing efficiency of an internal combustion engine.

WRIST PIN — The journal for the bearing in the small end of an engine connecting rod which also passes through piston walls; also known as a piston pin.

NOTES

NOTES

NOTES

ASE
CERTIFIED™

WE SUPPORT VOLUNTARY TECHNICIAN CERTIFICATION